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CANADIAN SMALL HYDROPOWER HANDBOOK:
BRITISH COLUMBIA REGION

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SMALL HYDROPOWER HANDBOOK FOR BRITISH COLUMBIA

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INTRODUCTION

WHY SMALL HYDRO

British Columbia offers enormous small hydro potential to its inhabitants: one study identified about 2400 MW, with 550 possible sites near the grid.

Small Hydro is part of the history of British Columbia. Many early mills, mines and towns built some form of power generation from small hydro, in the late 19th and early 20th centuries; and waterwheels were used much earlier - in Ashcroft, in 1863, for example. Most of these old sites have fallen into disuse by now - rendered uneconomic in the 1950's by the availability of cheaper electricity through an expanding, province-wide grid; and by the availability of portable, flexible, low cost diesel generators.

Diesel generators are still cheap to buy - but the rise in the cost of oil has made them expensive to operate. And the province's electrical grid, while extensive, does not include a number of small communities, resource-based businesses, farmers, and lodge owners: people in out-of-the-way locations who are paying an enormous cost for their independent way of life. Such people are taking another look at water power, because it offers a stable, inflation-proof source of electricity, using proven technology.

Small hydro installations have, historically, been cheap to run but expensive to build. That is changing now, with smaller, lighter, and higher speed turbine equipment, lower cost electronic speed and load control systems, and inexpensive plastic piping. Capital investments are still higher than investing in diesel equipment of comparable capacity; but the long life and low operating costs of small hydro make it an attractive investment for many applications. Examples of such installations, built in B.C. during the past few years, include: Glacier Park (150 kW); Hoeya Hilton (37 kW); Nimmo Bay (40 kW); Hasty Creek (37 kW); Klemtu (650 kW); Kingcome (75 kW); and Rendell Creek Ranch. Some very small, and very successful units have been installed by entrepreneurs - a farmer in the Pemberton Valley, for example (25 kW). Other, larger units, have been build by entrepreneurs who then sell power on contract to a resource industry - Lancaster Resources (now Synex) at Moses Inlet, selling to Crown Lumber.

There are business opportunities in small hydro - and a number of people are catching on.

PURPOSE OF THIS MANUAL

This book is written to assist people who are interested in developing a small hydro opportunity. It will be especially useful to people with small sites that would not justify the expense of extensive professional engineering services. Even with small sites, such services may be advisable if you have conditions you do not fully understand. The book will provide you with the information you need to:

- evaluate the potential of a small hydro site;
- lay out the site;
- apply for necessary licences and permits;
- get financing;
- select and install equipment; and
- understand the equipment, so that you can operate and maintain the system yourself.

The emphasis in the book is on doing as much as possible yourself, thus keeping capital costs as low as possible. However, advice on seeking professional help is also included - and the information contained in these chapters will be invaluable to you in dealing with any consultants and contractors you hire. Actual construction details are not included; general guidelines are given, along with pointers on what help can be expected from a construction contractor.

The book does not assume any previous acquaintance with the subject. Mathematical procedures are generally limited to multiplication and division for the fundamentals. (More sophisticated procedures may yield greater accuracy, but the simpler procedures outlined here should be sufficient for the scope of projects intended.)

A hydroturbine generator can by very small, like the alternator for a car (c. 500 Watts); or it can be very large, like the units at the Revelstoke Dam (several thousands of millions of Watts). Microhydro (1-100 kW) and mini-hydro plants (100 kW to 5 MW) are the smallest of the turbine generator units. This handbook is aimed mainly at installations of less than 500 kW, although it covers licensing requirements up to 20 MW.

The writers of the chapters that follow are all experts in their fields, and have all written as clearly and simply as possible. It will take time and study, however, to thoroughly understand each section of the book - especially the charts, tables, and graphs. The effort will pay off: your chances of bringing a project to a successful completion, producing reliable energy year after year, and significantly improving your cash flow, will be greatly enhanced.

COST OF DEVELOPMENT

Costs for smally hydro installations vary considerably, because sites, conditions and sizes are all different. In 1985, the typical development can range from $1,500 to $5,000 per installed kW. This would mean an investment of from $6,000 to $20,000 for the "typical" simple family home, which requires a peak demand of about 5 kW. (If that home were using electric heating, the demand would be from 12-20 kW.)

This handbook shows how to estimate the installation cost, and how to balance design tradeoffs, cost, and projected energy production.

You can significantly reduce costs by clever management, procurement, and hard work. The system at Rendell Creek Ranch cost only $25,000 for a 150 kW system - less than $200 per kW - because the community did most of the work itself and was able to buy and rebuild used equipment.

In approaching costs, remember that there are two basic types of developers: those who are interested in generating to meet only their own needs, regardless of the site's potential; and those who want to get as much as possible out of the site. Costs for the former developer will generally be lower because the system will be smaller, and geared both to minimum requirements and minimum flow. Investment for the latter will be higher, but the per kW cost may be less.

ORGANIZATION OF THIS MANUAL

You are encouraged to peruse the book and gain a general knowledge of its contents before starting actual development.

Chapters One, Two and Three represent the major steps for any site development. Chapter Four then treats dams, intakes, penstock, turbines and all equipment associated with the manufacture of a small hydro site, in considerable detail.

Chapter Five serves as a guide to developers on the legal aspects of permits, licences and insurance. This is a weighty section, but an understanding of the requirements is essential.

Chapter Six, on Economics and Financing, takes you through the economic feasibility of the project and helps you decide on the economics of the project.

Chapter Seven is subtitled "Getting Started". It gives the developer some practical tips on the many logistical steps necessary to carry through with the project, once it is designed. It will help get the project started - and help you make sure it is completed.

Chapters Eight and Nine are specialized chapters on Low Head and Cold Weather Considerations. If you are working under either of these constraints, these chapters should be read carefully.

Chapter 10 outlines the requirements for setting up a utility, should you wish to sell your surplus power.

New sections have benn added to incorporate recent developments:

- Grid Connections, Section 4-35 includes information on BC Hydro's power purchase policies and activities, and may be of assistance to small hydro developers.

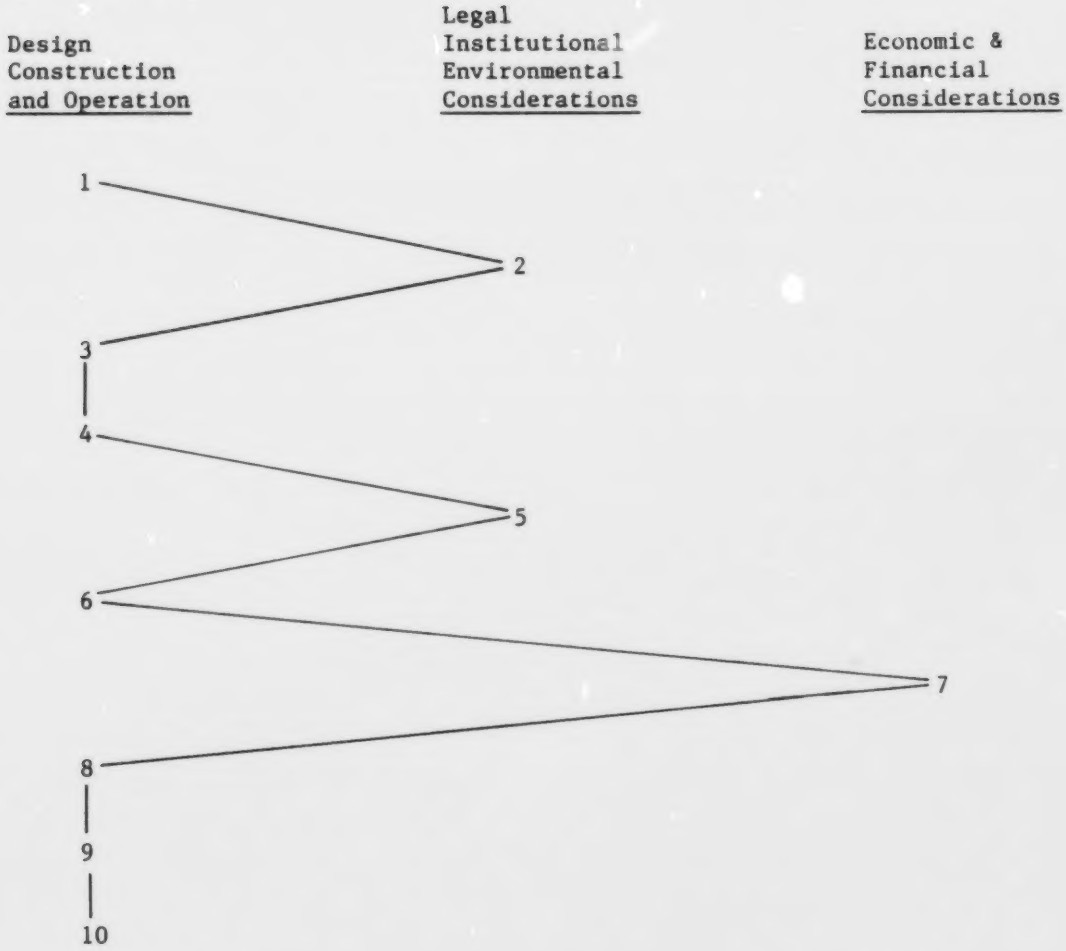
- Very Small Systems, Section 4-38 is new. Systems less than 2 kW can meet small loads of modest residences, cottage and cabins, often combining small hydro with battery storage.

Here is a possible event sequence for the conceptualization of a small hydro project. It may help you to decide how to get started.

You will notice that you have to go through several chapters two or even three times. This is because you will need to refine your cost estimates, designs and figures as your knowledge of the project grows.

Decision Points

1. Review complete book. Read Chapter One in detail and decide if you project is worth pursuing. Develop preliminary design ideas and costs.
2. Make preliminary contact with the provincial water licencing branch.
3. Read Chapter Two and get a thorough knowledge of the site and streamflow data.
4. Read Chapter Three and do the worksheets. By this time you should have a good idea whether you have a worthwhile project.
5. Make a formal application for water licence and any other legal requirements. Don't put this off. Contact the Department of Fisheries, the Ministry of Lands, and any other agency that may be applicable.
6. Read the rest of the book. Start getting prices for the equipment and work you will need.
7. From Chapter Six, do a detailed financial statement and complete the worksheets. You will need these if you have to go to the bank to borrow money.
8. Write down all you know about the project and make sure you have covered everything.
9. Build.
10. Operate. Don't forget to allow a "sinking fund" for operation and maintenance costs.


Design Construction and Operation
Legal Institutional Environmental Considerations
Economic & Financial Considerations

L'hydro électricité de faible puissance - Pourquoi faire?

En Colombie-Britannique, le potentiel relatif aux centrales hydro-électriques de faible puissance (petites centrales) est énorme et représente environ 2 400 MW. Qui plus est, 550 sites aménageables se trouvent à proximité du réseau.

L'hydro-électricité de faible puissance est intimement liée à l'histoire de la Colombie-Britannique. À la fin du XIX^e^ siècle et au début du XX^e^, beaucoup d'usines, de mines et de villes avaient recours à une forme quelconque de production d'énergie hydro-électrique, et à cet effet, s'étaient dotées de petites centrales de divers types. La roue à aubes date de bien avant; la municipalité d'Ashcroft, par exemple, l'utilisait depuis 1863. Ces équipements sont pour la plupart tombés en désuétude, notamment à partir des années 50, lorsque la province a commencé à se doter d'un réseau capable de produire de l'électricité à meilleur marché, et lorsqu'ont fait leur apparition les génératrices diesels portatives, dont on appréciait la souplesse et le coût relativement modique.

Les génératrices diesels sont encore assez bon marché, mais la hausse du prix du pétrole a rendue leur coût d'exploitation prohibitif. De plus, même si le réseau d'électricité de la province est très étendue, plusiers collectivités de petite taille, des entrprises vouées à l'exploitation des ressources, des agriculteurs et des hôteliers sont encore privés de ce service et doivent payer très cher du fait qu'ils sont isolés. Ces "laissés pour compte" se sont donc rabattus sur l'eau, qui leur offre une source d'électricité garantie, à l'abri de l'inflation, et exploitable au moyen d'une technologie éprouvée.

Jusqu'à récemment, il était relativement peu coûteux d'exploiter une petite centrale hydro-électrique; ce qui coûtait cher, c'était de la construire. Heuresement, cette situation est en train de changer, car l'industrie fabrique maintenant des turbines moins encombrantes, plus légères et plus rapides, des régulateurs électroniques de vitesse et de charge moins coûteux, ainsi que des conduites en plastique bon marché. L'investissement initial demeur cependant plus élevé que celui qu'exige un équipement diesel de même capacité. Néanmoins, la longue durée et les faibles coûts d'exploitation des petites centrales hydro-électriques en font un investissement séduisant dans bien des cas. Au nombre des installations de ce type qui ont été construites en Colombie-Britannique depuis quelques années, mentionnons celles de Glacier Park (150 kW), de Hoeya Hilton (37 kW), de Nimmo Bay (40 kW), de Hasty Creek (37 kW), de Klemtu (650kW), de Kingcome (75KW) et de Rendell Creek Ranch. Quelques unités de très faible puissance - mais combien utiles - ont été instalées par les exploitants eux-mêmes, comme cet agriculteur de la vallée de Pemberton qui en a construit une de 25 kW. Certains particuliers en ont construit de plus puissantes, pour ensuite vendre l'éclectricité, à contrat, à des entreprises d'exploitation de ressources naturelles; il suffit de citer comme exemple la société Lancaster Resources (maintenant Synex) qui a un contrat avec la société Crown Lumber, à Moses Inlet.

L'hydro-électricité de faible puissance ouvre donc des débouchés commerciaux, et plusiers savent en profiter.

Objet de ce guide

Ce guide a été rédigé à l'intention de ceux qui songent à aménager un site hydro-électrique de petite envergure. Il sera particulièrement utile dans le cas d'une installation de faible puissance ne justifiant pas de frais élevés d'ingénieurs professionnels. Toutefois, même s'il s'agit de faible puissances, il est préférable de fair appel à des spécialistes quand il est difficile d'évaluer les conditions qui prévalent. Ce guide vous fournira toute l'information nécessaire pour:

- Evaluer le potentiel d'un site hydro-électrique de faible puissance;
- Etablir le plan d'aménagement;
- Faire la demande des licences et permis nécessaires;
- Obtenir des fonds;
- Choisir et installer l'équipement;
- Connaître l' équipement pour le faire fonctionner et l'entretenir vous-même.

Notre but est de vous aider à accomplir le maximum vous-même, de manière à limiter autant que possible les coûts en capital. Parfois, nous vous conseillons de faire appel à des spécialistes: l'information contenue dans ce guide vous sera d'une aide précieuse lorsque vous aurex à traiter avec les experts-conseils et les entrepreneurs que vous engagerez. Vous n'y trouverez pas de détails pratiques sur la façon de construire votre centrale, mais nous vous indiquons les grandes lignes à suivre et vous donnons certains renseignements sur le type d'aide que vous pouvez obtenir d'un entrepreneur en construction.

Pour comprendre ce guide, vous n'avez besoin d'aucune connaissance préalable du domaine. Les formules mathématiques employées pour exécuter les calculs fondamentaux se limitent généralement à des multiplications et à des divisions. (Vous pourriez évidemment obtenir des résultats plus précis avec une méthode plus compliquée, mais la méthode simplifée que nous vous proposons devrait amplement suffire, compte tenue de l'envergure des projects auxquels elle s'adresse.)

Le groupe électrogène (génératrice et turbines hydrauliques) peut être de faibles dimensions comme celui de l'alternateur d'une voiture (environ 500 W); il peut aussi être très gros, comme ceux qui équipent le barrage de Revelstoke (plusieurs milliards de Watts). Les micro-centrales (d'une puissance de 1 à 5 kW) et les mini-centrales (de 100 kW à 5 MW) représentent le bas de l'échelle quant à la puissance des groupes électrogènes. Dans ce guide, nous nous intéressons pricipalement aux puissances inférieures à 500 kW, quoique, au chapitre des demandes de licences, nous couvrons tous les cas jusqu'à 20 MW.

Les auteurs des différents chapitres de ce guide sont tous des spécialistes dans leurs domaines; tout a été écrit avec le plus de clarté et de simplicité possible. toutefois, il vous faudra beaucoup de temps et d'études pour comprendre à fond chaque partie du guide et, plus particulièrement, les illustrations (cartes, graphiques et tableaux). Mais tous vos efforts seront récompensés: vous augmenterez de beaucoup vos chances de mener votre projet à terme, de vous assurer pour de nombreuses années une source d'énergie fiable, et d'accroître vos économies.

Coût de construction

Le coût de construction des petites centrales hydro-électriques varie considérablement, en fonction du site, des conditions qu'on y trouve et de la puissance recherchée. En 1985, le coût d'aménagement pouvait se situer entre 1 500 et 5 000 $ par kW installé, ce qui représentait un investissement de 6 000 à 20 000 $ pour une maison unifamiliale type,dont la demande de pointe pouvait atteindre 5 kW. (Si cette même maison se chauffait à l'électricité, sa demande aurait été de l'ordre de 12 à 20 kW.)

Ce guide vous indique comment calculer le coût d'insallation et, aussi, comment concilier différents aspects de votre project, comme les compromis que vous devez faire dans les plans d'aménagement, les coûts que vous aurez à payer et l'énergie que vous escomptez produire.

Vous pourrez réaliser des économies appréciables, à condition de faire preuve de discernement dans la gestion du project et les achats que vous ferez, et de ne pas ménager vos efforts. La centrale construite à Rendell Creek Ranch, d'une puissance de 150 kW, ne coûte que 25 000 $, soit moins de 200 $ par kW, parce que la communauté a exécuté elle-même la majeure partie du travail et qu'elle a pu acheter et remettre à neuf du matériel d'occasion.

Au moment de calculer les couts de construction, rappelez-vous qu'il existe deux principales catégories de constructeurs: ceux qui cherchent à répondre uniquement à leurs propres besoins, sans égard au potentiel du site, et ceux qui veulent exploiter le site au maximum. Les premiers investiront en général moins d'argent, parce qu'ils auront un système de plus petite envergure, aménagé en fonction de la demande minimale et du débit minimal. Les seconds devront fournir un investissement plus élevé, mais le coût par kW sera peut-être inférieur.

Plan du guide

Nous vous conseillons de lire le guide une fois en entier, pour avoir une vue d'ensemble de son contenu, avant d'entreprendre les travaux.

Les chapitres 1, 2 et 3 exposent successivement les principales étapes à suivre dans n'importe quel projet d'aménagement. Le chapitre 4 fournit des renseignements très détaillés sur les barrages, les prises d'eau, les conduites forcées, les turbines et toutes les pièces d'équipement utilisées dans la fabrication d'une petite centrale hydro-électrique.

Le chapitre 5 donne des reseignements de nature juridique sur les permis, les licences et les assurances à obtenir. Cette section du guide sera peut-être plus ardue, mais vous devez absolument comprendre tout ce qui y est expliqué.

Le chapitre 6 porte sur les aspects économiques et le financement des petites centrales. Il vous aidera à déterminer la rentabilité de votre projet.

Le chapitre 7 vous donne des conseils pratiques sur les nombreuses étapes à suivre pour réaliser concrètement le projet. Il vous aidera donc à commencer sur un bon pied et à augmenter vos chances de mener le projet à terme.

Les chapitres 8 et 9 considèrent des cas particuliers, notamment la construction de centrales à faible hauter de chute et l'exploitation par temps froid. Nous vous conseillons de les lire attentivement si l'un ou l'autre cas s'applique à votre projet.

Dans le chapitre 10, nous indiquons à ceux qui voudraient vendre leurs surplus d'électricité comment mettre sur pied un service d'utilité publique.

Nous vous proposons ci-dessous une méthode parmi d'autres pour la conception d'un projet d'aménagement hydro-électrique de faible puissance. Elle pourra vous aider à déterminer par où commencer.

Etapes	**Conception, construction et exploitation**	**Facteurs juridiques, institutionnels, environnementaux**	**Facteurs économiques et financiers**
1) Parcourez le guide au complet. Lisez le chapitre en détails et demandez-vous s'il vaut la peine de poursuivre le projet. Faites-vous une première idée du plan d'aménagement et des coûts.	1		
2) Etablissez des contacts préliminaires avec la Commission provinciale des eaux.		2	
3) Lisez le chapitre 2 et recueillez toutes les données au sujet du terrain et du cours d'eau.	3		
4) Lisez le chapitre 3 et établissez les feuilles de travail. A ce stage-ci, vous devriez avoir une bonne idée de la valeur du projet.	4		
5) Faites vos demandes officielles de permis auprès de la Commission des eaux et soumettez-vous à toutes les autres exigences juridiques. Ne sous-estimez sourtout pas l'importance de ces démarches. Contactez le ministère des Pêches, le ministère des Terres et tout autre organisme compétent.		5	
6) Lisez le reste du guide. Commencez à obtenir les prix du matériel et des services dont vous aurez besoin.	6		

	Conception, construction et exploitation	Facteurs juridiques institutionnels, environnementaux	Facteurs économiques et financiers
7) A partir du chapitre 6, établissez un état financier détaillé et remplissez les feuilles de travail. Vous en aurez besoin si jamais vous avez à emprunter de l'argent.			7
8) Couchez par écrit tout ce que vous savez sur le projet et assurez-vous d'avoir pensé à tout.	8		
9) Commencez la construction de la centrale.	9		
10) Procédez à l'exploitation de la centrale. N'oubliez pas un "fonds de prévoyance" pour les coûts d'exploitation et d'entretien.			

1 ENERGY FROM WATER - IS YOUR PROJECT WORTH PURSUING?

1.1 INTRODUCTION

Perhaps you are living close to a stream and you are considering building a small hydro project on it. Or perhaps you are starting to plan a project and you are looking for a suitable stream. In either case this chapter will help you.

Chapter One covers:

(a) The fundamentals of providing electrical energy from water;

(b) the process of selecting a suitable stream and a site for a hydro project;

(c) the simple calculations for helping you to decide whether you should continue planning your project, or whether you should start looking for some other way of getting electricity; and

(d) the costs, procedures and time requirements of hiring an engineer to do the preliminary work.

Probably your most valuable experience is to have lived next to a stream for several years and to have noted the fluctuations in its flow: how high and low it can go, how soon it reacts to a rainstorm, and how the stream changes its course when in flood. However, without this background knowledge you will still be able to build a good hydro project.

To help you decide whether or not to continue with your the project, you will be asked to

(a) estimate the power you need;
(b) stimate the streamflow available;
(c) measure or estimate the head available on the stream;
(d) estimate the power and energy available from the stream;
(e) make a preliminary layout of your project;
(f) make a preliminary estimate of the cost of your project; and
(g) decide: "Is your project worth pursuing?"

Each time you make an estimate or calculation, you should enter it in Table 1.3, "Project Data Summary" in Section 1.11, at the end of this chapter.

If you have already decided to continue planning, you should still skim through this Chapter and check that you have the data listed under all the headings in Table 1.3.

1.2 YOUR POWER REQUIREMENTS

First, you need to estimate how much power and energy you use at present, and how much you will use, say, ten years from now.

The power and energy you use are both called "load". Power is measured in watts or kilowatts (kW) 1000 watts. Energy is power multiplied by the length of time it is used; energy is measured in kilowatt-hours (kW.h).

Example:

> Suppose you use an electric kettle that is rated at 1500 watts, and you use it for three minutes, five times a day. The load would be
>
> $$\text{power} = 1.5 \text{ kW}$$
> $$\text{energy} = \frac{3}{60} \times 5 \times 1.5 = 0.38 \text{ kW.h per day}$$

If you already have a source of electric power -- a diesel generator or a connection to a B.C. Hydro or West Kootenay Power line -- you know your loads. You may also know how your loads fluctuate during the year.

For estimating future loads, you should know that load management can reduce your maximum load and consequently the size of the hydro plant needed to replace your existing diesel generator. This is explained next.

1.2.1 Load Management

Normally, electric loads vary throughout the day. Figure 1.1 shows typical load variations for a 3 bedroom home all-electric (except cooking stove), in winter. Note the peaks at 8 am and 6 pm.

However, not all those loads need be on at the same time. For instance, if the fridge, freezer, hot water heater and space heating were turned off at 6 pm, the peak load could be reduced to about 8.5 kW, a 65 percent reduction.

This is called load management, and it can be done automatically by an electronic control unit. Load management enables you to reduce the size (kW) of your power plant, while still providing enough energy (kW.h) to supply the fridge, freezer, etc. during off-peak times.

Here is another example where load management can reduce the size of a hydro plant: assume you have a diesel generator for lights and appliances, and oil or propane for heating. If you want to build a hydro plant to provide energy for everything - lights, appliances and heating - you may find that with automatic load management, you can build the hydro plant just the right size (kW) for the lights and appliances, without increasing the plant size for the heating loads. The heating loads would be on most of the day but would be turned off during peak load times.

Load management is discussed in greater detail in Chapter 3. For now you should understand that with an electronic load management unit, the peak load is less than the sum of all the rated loads.

Normally some degree of load management is used in mini-hydro plants. The loads shown in Table 1.1 assume some degree of load management.

1.2.2 Load Estimates

An approximate estimate of the load will do at this stage. A more accurate estimate will be made in Chapter 3.

Using Table 1.1 to estimate your peak winter and summer loads, select a value within the ranges given. These ranges indicate the difference in loads due to different living styles and different climates. Take account of the appliances you have, compared to those listed in the table, and the conservation or extravagance in your use of electricity. Also consider the climate where you live: you will use more electricity in the interior and northern parts of B.C. than you will on the coast, on Vancouver Island, or in the Lower Mainland.

Following the example below, write down your expected future peak load value for the winter (November-April) and summer (July-October). Use a future of 10 years time or whatever time span you wish to consider for the hydro plant.

If you want to make a more detailed estimate, turn to the section on "Power and Energy Requirements" in Chapter 3. Do this only if you want to learn more about load management: it gets quite complicated.

Example:

> A single family house with 2 bedrooms and workshop - electric lights, washer, drier, fridge, freezer, kitchen appliances (no oil, propane or wood cooking stove), baseboard and hot water heating, table saw, small hand tools.

From Table 1.1:

> (In this example case 3B, a 3 bedroom house without back-up for heating, is used to allow for additions in the future.)

	Example	Your Expected Loads
Winter Maximum Load	12 kW	.... kW
Summer Maximum Load	5 kW	.... kW

(Write these values at the top of Table 1.3)

1.2.3 Energy Conservation

Do you conserve energy as much as you can? Have you considered the following ways of reducing your energy consumption, and thereby reducing your costs?

- upgrading insulation in basements, floors, walls, cedilings and attic;
- adding storm windows or double or tiple glazing;
- reducing air leaks by caulking and weatherstripping round dorrs and windows;
- servicing the oil or propane furnace and water heater;
- insulating the hot water tank and pipes;

1.3 POWER AND ENERGY DEFINITIONS

The methods for calculating power and energy that are available from a stream are covered in this section.

1.3.1 Power

The calculation of the actual power from your stream is covered in Section 1.6, after you have measured or estimated the flow and head.

The theoretical power equation (Equation 1-1) is

$$P = Q \times H \times e \times 9.81 \text{ Kilowatts (kW)} \qquad (1\text{-}1)$$

Where:

P = Power at the generator terminal, in kilowatts (kW).
Q = Flow in pipeline, in cubic metres per second (m^3/s).
H = The gross head from the pipeline intake to the tailwater, in metres (m) (see Figure 1.2).
e = The efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator, expressed by a decimal (ie 85% efficiency = 0.85)
9.81 = Constant for converting flow and head to kilowatts.

All power systems produce less power than is theoretically available. The losses in a hydro plant are:

(a) losses in energy caused by flow disturbances at the intake to the pipeline, friction in the pipeline, and further flow disturbances at valves and bends; and

(b) losses of power caused by friction and design inefficiencies in the turbine and generator.

The energy losses in the pipeline and at valves and bends, are called head losses: they represent the difference between the gross head and the net head that is available at the turbine (see Figure 1.2).

The head losses in the pipeline could range from 5 percent to 15 percent of the gross head, depending on the length of the pipeline and the velocity of the flow. The maximum turbine efficiency could range from 80 percent to 90 percent depending on the type of turbine, and the generator efficiency will be about 90 percent.

At this stage in the planning of your hydro plant, the head losses can be combined with the losses in the tubine and generator, and an overall plant efficiency of 60 percent (or $e = 0.60$) can be used. Using $e = 0.60$ in Equation 1-1, the actual power output at the generator can be calculated from the following Equation 1-2:

$$P = Q \times H \times 5.9 \text{ (kW)} \qquad (1\text{-}2)$$

The Power Output Nomograph in Figure 1.3 enables you to make quick estimates of power, flow or head.

Example:

Suppose you know the lowest flow (discharge) in the stream (say 0.1 m^3/s or 100 L/s), and you know where to put the intake and powerhouse so you can estimate the head (say 10 m).

	Example	Your Values
Flow	100 L/s	.... L/s
Head	10 m	.... m

In Figure 1.3 mark a point (in pencil) at a flow of 100 L/s on the DISCHARGE (left) scale; on the HEAD (right) scale mark a point at a head of 10 m. Draw a straight line between the two points and where this line intersects the POWER (middle) scale is the estimated power, in this case 5.9 kW.

Power	5.9 kW	.... kW

If you have been using your own values of flow and head, and find that the power output is not enough for your power requirements, don't worry: you're just trying out the nomograph. Later in this chapter you will make the proper calculations.

Other ways of using the nomograph are:

(a) to find the necessary flow, provided you know your power requirements and can estimate the head available on the stream. Extend a straight line from the HEAD scale through the POWER output scale and onto the DISCHARGE scale, or,

(b) to find the necessary head, provided you know your power requirements and can estimate the minimum flow in the stream.

1.3.2 Energy

The equation to calculate energy is

E = P x time

Where:

E = Energy, in kilowatt - hours (kW.h)

P = Power, in kilowatts (kW)

Time = Time while power is generated or used

Example:

If you run a 1000 watt (1 kW) electric heater for 5 hours you use 5 kW.h of energy.

1.4 DATA COLLECTION

Streamflow, head and pipeline length must be estimated or measured, before you can calculate the power that could be developed from a stream. Streamflow is the most difficult to measure or estimate. However you should have an understanding of its sources, its fluctuations and flow measurements or estimates.

1.4.1 Streamflow

Streamflow comes from either rain or melting snow, but not all the rain or melting snow immediately becomes streamflow. There are losses caused by evaporation from the ground surface, transpiration by the vegetation whose roots have absorbed moisture from the ground and from seepage or surface water into the ground to become groundwater. This groundwater can take weeks or months to appear as streamflow, and is therefore not available for power immediately after rain or snowmelt. However, this groundwater is important, the major component of the streamflow during dry periods in the summer or winter. A hydro project should be designed for these dry, low flow periods. It is advised that you check both Fisheries and Water Licenses statutes of the creek prior to doing much work, it might belong to someone else.

Streamflow Fluctuations

We all know that streamflow fluctuates, often daily, always seasonally and yearly. To visualise these fluctuations, values of flow are plotted against time, as shown on Figure 1.4 (A and B) these plots are called hydrographs.

In Figures 1.4.A and 1.4B, hydrographs of flows in 1980 are shown for six rivers in five different parts of B.C. Notice the different patterns of flow in different parts of the province. The simplest pattern is for Beatton Creek in southeast Interior (Figure 1.4A):

(a) low flows in January to March (cold weather).
(b) rapidly increasing flows in April (snowmelt).
(c) high, erratic flows in May and June (snowmelt plus rain). steadily decreasing flows in July and August (no further snowmelt).
(d) low flows again through the winter.

Brouse Creek (Figure 1.4A), in the same area as Beatton Creek, is much smaller. The pattern for these two creeks is similar except that in Brouse Creek the major snowmelt period is in May only.

Moving westward to the Coquihalla River (Figure 1.4A), the effect of winter rain is reflected in the extremely sharp peaks in December. A pronounced snowmelt period lasted from April until June, and prolonged low flow periods occurred in January and February and again between August and October.

In the North, the Cottonwood River hydrograph (Figure 1.4B) shows the prolonged low flows caused by low temperatures from December through to the end of April.

West of the Coast Mountains, the Little Wedeene River hydrograph (Figure 1.4B) shows the effect of heavy rain from September to December. The snowmelt period, April to June is not so obvious because of the erratic rain peaks superimposed. Short periods of low flows occurred in most months January - March and August - October.

In the Northern part of Vancouver Island, the pattern of flows for the Ucona River is less distinct; erratic flows during the winter (rain and snowmelt), fairly steady flows April - June (snowmelt), then decreasing flows to September (little rain).

Knowing these patterns will help you choose the right time of year to measure low flows and average flows. You will also recognize the relation between low, average and high flows; this will enable you to check the magnitude of your measurements or estimates.

Streamflow Measurements and Estimates

While many larger streams and rivers in B.C. have gauges installed by Federal or Provincial Government agencies, it is unlikely that there will be a gauge on your stream. You will probably have to measure or estimate the flow.

There are several ways to measure flow:

(a) use a float to measure velocity and a level and tape to measure the stream cross-section,

(b) construct a weir (A weir is a low dam over which the water flows) across the stream and measure water levels or,

(c) use a flow-meter to measure velocity, and a level and tape to measure the stream cross-section.

Using a float is the easiest but the least accurate method. Building a weir or using a flow-meter are the best methods for establishing a semi-permanent measuring station to obtain flows for several months or years. At this stage in the planning process, you should use the float method described in Supplement 1.1 (at end of this chapter).

What flows should be measured? This will depend on the amount of water the hydro plant will take from the stream compared to the minimum flow in the stream. You need to get an overall picture of the variations in the flow of the stream. But the lowest flow is usually the most important because it can limit the maximum power that can be produced.

At this stage, you don't know how much flow the hydro plant will take. But it is helpful, when deciding what stream flow to measure, to keep in mind three situations:

1. The stream is large and only a small portion of the lowest flow is needed for your hydro plant. If you know that you will always have enough water for the plant. You don't have to measure the flow; you can go onto the next section on "Head", however, if in doubt at all measure the flow. Streamflow is difficult to eyeball.

2. The minimum flow in the stream is about equal to or is slightly more than the flow needed to produce maximum power. You should measure the lowest flow, then estimate the minimum flow that can be expected in the stream: this is explained later.

3. The minimum flow in the stream is less than the flow needed to produce maximum power, and water will have to be stored for part of the year (water storage is discussed in Section 1.6.3), or a diesel generator will have to be used when the flow is low. In this case, you need to know the low and average flows. You should measure the lowest flow you can and also the average flow, several times. If the stream dries in the summer or winter, measure the lowest flow about one month before it normally dries.

Measure the flow when it is low and/or average, according to the three guidelines above. Make several measurements on different days.

To help you decide when to measure low flows and average flows, check the hydrographs in Figure 1.4 (A + B). Select the hydrograph newest to your area and find the months which had the lowest flow and the closest to the average flow.

For example, look at the Ucona River on Vancouver Island, August had the lowest flow, and May and June had flows close to the average. Watch out for sudden increases in flow caused by heavy rain or rapid snowmelt. If you plan to measure flow, you may have to wait a few days for the flow to return to average or low levels.

Obviously, you may have to wait up to six months to measure both the lowest flow and the average flow. Having started to read this book, you may want to get on with your calculations. If that is so, measure the lowest flow you can at this time, then estimate the lowest flow you would expect to see in the stream.

There are two ways to estimate the lowest flow to be expected in a stream:

(a) from low water levels noted or remembered by someone who has lived in the area for several years; or

(b) from records of flows on a nearby stream. These records are available at a Regional Office of the Ministry of Environment, or from Water Survey of Canada (see Supplement 2.1 at the end of chapter 2).

Ask the Ministry of Environment or Water Survey of Canada for the lowest recorded 5-day flow in a stream near yours. Also, ask them how the lowest flow compared to the flow on the day when you made your measurement. For the comparison stream, calculate the ratio of the lowest flow divided by the flow at the time of your measurement. Then multiply this ratio by the measured flow pm upir stream to give you an approximate value for the lowest flow in your stream.

Example:

Suppose your hydro project is in the Northern part of Vancouver Island: take the Ucona River as a reference. You measured a low flow in your stream on August 25, 1980, and you want to estimate the lowest flow to expect in your stream over a period of 10-20 years.

Measured flow in your stream Aug 25, 1980: 100 L/s
Recorded flow in Ucona River Aug 25, 1980: 2.32 m^3/s (2320 L/s)
Lowest recorded 5-day flow on the Ucona
River over a period of 24 years: 0.53 m^3/s (530 L/s)

Ratio for Ucona: $\frac{\text{lowest recorded 5-day flow}}{\text{flow on August 25, 1980}} = \frac{530}{2320} = 0.23$

Lowest flow expected on your stream: 100 x 0.23 = 23 L/s

Whenever you measure a flow, you keep a record of the date (so you can compare your flow with the flow in another stream), and the level of the water surface at some selected point in your stream (this is explained in Supplement 1.1).

Write your flow measurements in the following table and also in Table 1.3.

Streamflow Summary:

Minimum Flow Measured: .... L/s or m^3/s
Date: ....
Normal Flow Measured: .... L/s or m^3/s
Date: ....
Maximum Flow Measured: .... L/s or m^3/s
Date: ....
Estimated Lowest Expected Flow (Qmin):.......................... L/s or m^3/s

1.4.2 Head

Gross head is approximately the vertical distance between the level of the water at the upstream end of the pipeline (or in the forebay) and the level of the centre of the turbine (see Figure 1.2). In this section, you will be measuring, or estimating, the gross head.

If the gross head is less than about 10 m, the variations in the levels of the forebay and tailwater will significantly effect the value of head: a 1.0 m variation in the forebay level will make a 10 percent difference in power output. So, if the head is less than 10 m, write down where you assumed the forebay level to be, when you measured the head.

Before you can measure the head you must know the locations of the pipeline intake and the powerhouse. However, if you don't yet know those locations you can still estimate the gross head that you need to produce the power you want. Using the nomograph in Figure 1.3, plot the power you need and the minimum flow of the stream, and the nomograph will give you the gross head.

Example:

	Example	Your Values
Power Required	20 kW	.... kW
Minimum Streamflow	100 L/s	.... L/s

Draw a straight line (in pencil) between the Discharge (Example:

100 L/s and POWER (Example: 20 kW). Extend the line to cut the Head axis, and read the head (Example: 34 m).

Head .... 34 m .... m

Now enter your own values of Power and Minimum Streamflow, and find the Head required.

Back to your stream. On a map, locate the powerhouse as low down and as close to the load (house, camp, etc.) as possible. If the water from the turbine must be returned to the stream, the powerhouse should be close to the stream. Using the contours on the map and the head just calculated, find a place on the stream for the intake, preferably at the top of a steep part of the stream. Then go into the field and locate the powerhouse and intake. Use surveyor's tape, or some other flagging to mark the powerhouse, intake and pipeline locations.

Head Measurement

If the head required is less than 10 metres, you must measure it accurately. Use a hand level or surveyor's level. If you don't own either of these, you might be able to borrow one from a surveyor, contractor, or logger. The use of these instruments is explained in Supplement 1.1 at the end of the chapter).

For a head between 10 metres and 30 metres you could use a hand level or an altimeter (Supplement 1.1 explains how to use an altimeter).

If the head is more than 40 metres you could find the head from a large-scale topographic map: a 1:50,000 scale map has contours at 40 metre intervals, so you need a larger scale. See Chapter 3 and Supplement 2.1 for suggestions on where to get maps.

In Table 1.3 enter the gross head that you have measured.

1.4.3 Pipeline Length

A fairly accurate measurement of the pipeline length is important if it is longer than, say, 100 metres. The head losses in the pipe become significant for a pipe larger than 100 metres. A larger pipe is needed, and the pipeline cost becomes a large part of the total project cost.

The most accurate way to measure the length is to use a tape (30 metres or more), or light rope. Surveyors use a nylon cord (which they call a chain), marked off in 10 metre lengths. They drag the chain through the bush without coiling it: this prevents knotting.

If the pipeline is longer than 300 metres, you could measure the length on a larger scale map. Make an allowance for the fact that the actual length along the ground will be greater than the length you have measured on the map. The actual pipeline won't be as straight as the line on the map and the pipeline will be sloping. You can either calculate the slope correction, or add 10 per cent to the length measured on the map.

1.5 INSTALLATIONS

This is the time to decide on a preliminary arrangement for your hydro project: The locations of the intake, dam, pipeline and powerhouse: and the type of turbine needed. If possible, get a map of the area from a government office, a local logging company or a forester with the Ministry of Forests maps, and where to get them are discussed in Appendix G at the end of Chapter 3). Draw on the map the intake, dam, pipeline, powerhouse, and transmission line. This will help you define the layout and help you describe the project to someone else, such as a small hydro owner, a bank manager, a person in the Water Rights Branch Office:

To help you decide on a layout, the following considerations will be covered in this section:

(a) run-of-river versus storage projects;
(b) typical project layouts;
(c) project structures ie. dam, weir, intake, canal, pipeline, powerhouse, tailrace;
(d) to suitable turbines (Cross-flow, Francis and Pelton turbines) for low, medium and high head projects;
(e) existing dams and;
(f) transmission lines.

1.5.1 Run-of-River versus Storage Projects

A run-of-river project is built to use some or most of the flow in a stream depending upon the flow throughout the year. No attempt is made to store water for the dry periods. A run-of-river project would not normally have a dam, other than an intake weir, which is a very low structure at the intake. The intake weir keeps the water in the stream high enough to fill the pipe at all times.

A storage project on the other hand, has a dam, which creates a water storage reservoir to maintain flow in the stream during low flow periods. The intake to the pipeline might be part of the dam or separate from it, depending on the location of the pipeline.

1.5.2 Project Layouts

The layouts shown in Figure 1.5 are typical of most projects that would be built in B.C.

Layout #1 is the simplest, with a weir or low dam across the stream, an intake to the pipeline, the pipeline, powerhouse and tailrace channel (each structure is described in more detail in Section 1.5.3). The weir forms a pond to ensure that there is always water above the pipe at the intake; the pipeline carries the water, under pressure, to the turbine in the powerhouse; the tailrace channel carries the water from the turbine back into the stream, or into a lake or the sea.

Layout #2 illustrates a possible cost-saving arrangement, whereby a canal or low-pressure pipeline is built to contour around a hillside, and a shorter high-pressure pipeline, called a penstock, is used.

Layout #3 shows a pipeline intake incorporated in a storage dam.

Layout #4 shows a situation where there is a lake suitable for a storage reservoir some way up the stream. A dam can be built at the lake to store water, which can be released down the stream during dry periods.

Layout #5 and Layout #6 show the layout of a low head plant where there is less than 10 m gross head. Notice that there is no pipeline or dam. Layout #5 shows the weir, intake and powerhouse combined into one structure. Layout #6 shows a power canal between the intake and powerhouse.

Many aspects of a low head plant are different from those of a higher head plant (head greater than 20 m): flows are higher, the turbine is larger, no pipeline is used. For these reasons low head plants are discussed separately in Chapter 8.

1.5.3 Structures

The structures of a hydro project are described in detail in this section. Guidelines for selecting sites for these structures are given in Chapter 2, Section 2.6. Suggestions are given below for estimating dimensions for some of the structures. This will enable you, in Section 1.8.1, to estimate the cost of your project.

Storage Dam

A storage dam, normally 3 m to 10 m high and constructed of earth or rock, should be designed by an engineer.

There are many different designs for earth and rock dams. A typical earth-fill dam, as shown in Figure 1.6, has a central section constructed of low permeable material supported on either side by higher permeable material. The material has to be carefully compacted in thin layers as it is built.

The pipe through the dam could continue to the turbine, or could discharge into the stream or a canal at the downstream side of the dam. There would be a valve at the upstream end of the pipe.

A spillway would be built into the dam to allow high flows to pass without overtopping the dam. The crest of the spillway would be lower than the top of the dam.

Intake Weir

Normally you would need to build a low weir (1 m to 2 m high) across the stream at the intake to the pipeline, to form a headpond (see Figure 1.6). This headpond would

(a) ensure a high enough water level to keep water always above the top of the pipe.
(b) allow some of the sediment in the stream to settle out before entering the sediment trap,
(c) allow an ice sheet to form, giving some protection against water freezing in the pipeline, and
(d) provide pondage (water storage) to compensate for one or two-day water shortages.

Water would flow over the weir most of the time.

While there are many ways to build a weir, concrete, rock-filled gabion and rockfilled timber-crib structures are the most common for small hydro projects (see Figure 1.6).

If the weir is built across a narrow part of the stream and founded on bedrock, a concrete structure would probably be the most economical. In other cases a concrete structure would probably be the most expensive, but it would also last the longest without maintenance.

A gabion is a wire-mesh box filled with rock. Assuming there is a good supply of rock at the site, only the wire-mesh need be bought and transported to the site. Gabions are not waterproof, so an impervious polyethylene membrane or asphalt sheeting would be laid on the upstream side. Fill would be placed on the upstream side to protect the membrane. A reinforced concrete cap should be placed on the top of the gabions to protect them from the water and debris passing over the weir.

A rock-filled timber-crib dam is often the least costly weir to build, especially if rock is available at the site and timber can be cut nearby. Timber or logs are placed in alternate directions and spiked where they cross (see Figure 1.6). The bottom logs should be anchored to the foundations, and the space between the logs should be filled with rock. Wooden sheathing is attached to the upstream face and the crest, and often sheathing is also placed on the downstream face. Low permeability fill should be placed upstream to reduce seepage through the dam and foundations.

Water in the headpond must be kept at a certain height (called submergence) above the top of the pipe, to prevent air entering the pipe. Values of submergence are given below:

Pipe Diameter	Submergence
less than 600 mm	1.0 m
600 - 1200 mm	1.5 m

(Pipe diameter is discussed in detail in the "Pipeline" section, which follows.)

The crest of the weir should be above the top of the pipe by an amount equal to 0.5 m plus submergence.

Intake

The intake to the pipeline can be a separate structure, part of the intake weir, or part of the storage dam. There are many types of intake. The sketch in Figure 1.6 shows the components of a typical intake.

To prevent sediment from flowing into the turbine, a sediment trap can be built upstream of the intake structure or within the structure; or immediately downstream, as a separate self-flushing tank built into the pipe.

A trashrack prevents floating debris from entering the pipe. Trashracks must be cleaned regularly.

Stop-logs or a valve should be provided to shut off the flow from the pipeline during maintenance or repair of the pipe, or closure of the turbine during cold weather. An air vent should be placed just downstream of the valve to prevent the pipeline collapsing when it is emptied with the valve closed.

The top of the intake should be at least 0.5 m below the top of the weir.

Pipeline

To help you determine the preliminary arrangement and cost estimate of your project, you also need to decide on pipe diameter, pipe material, above-ground or underground pipe location, pipe support and anchore blocks.

You need to know the diameter of the pipeline to estimate its cost in Section 1.8.1. The diameter can be read from the graph in Figure 1.7, by using your value of Qmin (from Section 1.4.1, or from Table 1.3) on the horizontal axis, then reading the diameter on the vertical axis.

Example:

	Example	Your Values
Pipe flow = Qmin	200 l/s	.... l/s
or	0.20 m^3/s	.... m^3/s
Pipe Diameter D	410 mm	.... mm

Write your value of pipe diameter in Table 1.3 for later reference.

Steel, cast iron, aluminum, polyethylene and PVC are materials used for small hydro pipelines and penstocks. Generally, for the higher head sites in B.C. (above 20 m head) polyethylene or PVC are used. When the head is greater than about 60 m, use of steel at the lower end (higher head) of the pipeline is more economical.

PVC pipe should be buried for protection from the sun's ultraviolet rays and polyethylene and cast iron pipes should be buried for potection against damage from falling trees or rocks, or from logging machinery. If air temperatures normally stay below -5C for more than five days at a time, the pipeline should be buried or insulated.

Supports must be provided for rigid pipes such as steel, cast iron, or aluminum, but the more flexible polyethylene can be laid directly on the ground or on wooden supports. Anchor blocks should be placed around the bends of all types of pipes. A thrust block should be built at the lower end of the pipeline, just upstream of the powerhouse.

Powerhouse

The size of the powerhouse is determined by the type and size of the turbine installed. Figure 1.6 shows typical layouts for Pelton and Francis turbines. A low head plant (less than 10 m head) looks quite different: See Chapter 8.

The substructure -- which consists of the pedestal of the turbine and generator, the draft-tube or discharge pit, and the floor slab - should be made of concrete. The superstructure -- which is above the floor and protects the machinery and electrical controls from rain, heat, cold and vandalism -- can be made of wood frame, metal frame, concrete block, log or self supporting metal panels. Make sure that the superstructure allows the turbine and generator to be installed and removed for repair.

Tailrace

The tailrace is a channel which leads the water from the turbine back into the stream, a lake or the sea. It should prevent the water from damaging any structure or the landscape.

1.5.4 Low, Medium and High Head

Low, medium and high head are terms used to indicate the most suitable type of turbine for the project. The various types of turbines listed in the table below are described in Section 4.15, "Turbines".

- Low Head	up to 10 m	Use: Cross-flow, axial-flow or propeller turbine
- Medium Head	10 m to 200 m	Use: Cross-flow, Francis, Pelton or Turgo turbine
- High Head	200 m to 1000 m	Use: Pelton, Turgo-impulse or Francis turbine

1.5.5 Existing Dams

If there is already a dam on a stream nearby, you should consider using it. First, find out who owns it, then try to assess what repairs would have to be done if you were to use it as an intake dam or a small storage dam. Could you incorporate in the dam an intake for a pipeline? You should have an engineer check the dam before further developing your plans for its use. You should also check with Water Management Branch as a changed use could require the dam to be upgraded.

1.5.6 Transmission Line

If your load (i.e. house, bunkhouse, sawmill, etc.) is more than 100 m from your powerhouse, you will need a transmission line, and probably step-up and step-down transformers. Transmission lines are expensive ($17,000/km or more) so always plan to put the powerhouse as close as possible to your load; however, they are less expensive than pipelines so a trade off must be made.

1.6 AVAILABLE POWER AND ENERGY

Now that you have measured, or estimated, the lowest expected flow (Qmin) and gross head (Hg), you can calculate the power and energy available from the stream. To calculate power, use the nomograph in Figure 1.3, or the power Equation 1-3, as explained in Section 1.6.1. The calculation of energy is explained in Section 1.6.4.

1.6.1 Firm Power

Firm Power is the power that is always available from the stream, even at times of lowest flow and lowest head. To calculate firm power you use the lowest expected flow in the stream (Qmin) and the gross head (Hg). In the case of a low head plant (less than about 10 m) in which the forebay level varies, the gross head should be measured to the minimum forebay level.

Using these new symbols for Q and H, the power equation (1-2) becomes:

$$\text{FIRM POWER (Pfirm)} = \text{Qmin} \times \text{Hg} \times 5.9\ \text{kW} \qquad (1\text{-}3)$$

Remember, in this equation, the overall plant efficiency is assumed to be 60 percent because of head loss in the pipeline, and turbine and generator efficiencies. The nomograph in Figure 1.3 was drawn from this equation.

With the values of Qmin and Hg that you have written into Table 1.3, use the nomograph in Figure 1.3 to calculate the firm power Pfirm.

Example:

	Example	Your Values
On the nomograph enter:		
Qmin	200 l/s	.... l/s
Hg	30 m	.... m
From the nomograph:		
Pfirm	35 kW	.... kW

Write your Pfirm value - the firm power available from the stream - into Table 1.3.

1.6.2 Design Capacity of Hydro Plant

The design capacity (or installed capacity) of your hydro plant is the maximum power it can produce. For this stage in the planning process, assume that the design capacity is made equal to the maximum load, using some load management, as discussed in Section 1.2.2. Also, assume that the plant can produce maximum output -- equal to the maximum controlled load -- when the flow in the stream is at its lowest. This means that the plant will be able to produce all the power you need, even during dry periods.

These assumptions are summarized:

Design capacity of plant (kW) = Maximum load (kW) = Firm power (kW)

This is a simplifying assumption that is satisfactory for the calculations in Chapter 1, a more detailed analysis is made in later chapters.

1.6.3 Storage Reservoir

If your hydro plant cannot produce enough power to meet your peak load when the streamflow is low, you can

(a) build a dam and create a storage reservoir, or
(b) Use a diesel generator or other source of power during low flow periods.

The stream might dry up completely in the summer or in the winter after several weeks of very cold weather. Even with a storage reservoir or an alternative source of power for these short no-flow periods, a hydro project might still be economic.

Decide if you want to build a storage dam or use an alternative source of power. If you already have a diesel generator, you might choose to use that. If there is a lake upstream of your planned pipeline intake, you might choose to build a small dam at the outlet of the lake to control storage.

You do not have enough information yet to calculate the volume of storage you require, or the height of the dam. How to calculate these is described in Chapter 3. Until then, if you plan to build a dam, follow the guidelines in Section 1.8.1 for including an allowance for the cost of the dam.

1.6.4 Energy

Next, estimate the average annual energy that you will use from your hydro plant. You will need this in Section 1.8.2 to estimate your hydro energy cost (cents/kW.h). By comparing this cost with the cost of alternative sources of energy, such as a diesel generator or energy from a B.C. Hydro or West Kootenay Power line, you can decide if you wish to build the hydro project.

The amount of energy that you will use from your hydro plant will depend on

(a) the design capacity of the plant, compared to the flow and head available in the stream, and

(b) the variations in your load (discussed in Section 1.2.1).

For each plant and stream, there is a specific set of conditions which has to be known before you can calculate accurately the average annual energy output.

At this stage you do not have enough data, and simplifications must be made.

If you wanted to generate constant power equal to your maximum load (assuming some degree of load management), the annual energy output would be:

$$E\ (\text{annual}) = P\text{design} \times 8760\ \text{kW.h} \qquad (1\text{-}4)$$

Where:

E (annual) = Annual energy output (kW.h).
Pdesign = Firm power (kW) calculated in Section 1.6.1.
8760 = Number of hours in a year.

However, your load will not be constant (as discussed in Section 1.2.1) and the design capacity of the plant (Pdesign) would probably be larger than your maximum load, to include the possibility of increased loads in the future. You will also have to shut down the plant for maintenance. For these reasons, your actual annual energy output will be less than indicated by Equation (1-4). To account for this, a Plant Factor (or Capacity Factor) is used:

$$\text{Plant Factor (PF)} = \frac{\text{Average power generated during year}}{\text{Plant design capacity (Pdesign)}}$$

The average annual energy output would then be:

$$E\ (\text{annual}) = \text{Pdesign} \times \text{PF} \times 8760\ \text{kWh} \qquad (1\text{-}5)$$

Plant factors describe the way in which a plant operates over a period of time, say, for several years.

For these preliminary estimates of average annual energy, use a plant factor of 80 percent. (A plant factor of 80 percent applies to a system with automatic load management. If you do not intend to use automatic load management, use a plant factor of 50 percent.)

Average annual energy is:

$$\begin{aligned} E\ (\text{annual}) &= \text{Pdesign} \times 0.8 \times 8760 \qquad (1\text{-}6)\\ &= \text{Pdesign} \times 7000\ \text{kW.h} \end{aligned}$$

Example:

In the previous examples in Section 1.6.1 we calculated the Firm Power output of a stream to be 35 kW. Assume that the plant is designed to produce maximum power equal to this Firm Power from the stream.

Using Equation (1-6), the average annual energy used is:

$$\begin{aligned} E\ (\text{annual}) &= 35 \times 7000\ \text{kW.h}\\ &= 245{,}000\ \text{kW.h} \end{aligned}$$

1.7 ADVISORS

Turbine manufacturers, pipe suppliers, contractors and electricians will give you free advice. Owners of small hydro plants, particularly those who have built their own, will usually be pleased to tell you about their experiences and offer advice.

1.7.1 Engineers

You can hire an engineer to do part or all of the design of the project. An engineer can

(a) advise on specific problems such as, safety of the existing dam you might want to use; foundations for a dam, pipeline supports or powerhouse; type of electrical or mechanical equipment;

(b) design certain structures such as a dam, pipeline supports, an electrical load control panel, or a turbine;

(c) make a preliminary study to confirm the feasibility of the project;

(d) prepare a feasibility report for a bank or investor from whom you want to borrow money; or

(e) design and supervise the construction of the project.

Guidelines on the cost of these services are given in Section 1.8.1, "Engineering Costs".

Before you hire an engineer, contractor or any other professional person, ask for an estimate of the cost of services and expenses to be paid. Ask him to write down exactly what he will do and how long it will take. Make sure you understand what he said he would do, and that this is what you want. When he's finished the job and you want him to do more, or he suggests doing more, again, ask for an estimate on the additional work. In that way you are in control of your expenses and you will avoid unpleasant surprises when you receive his bill.

The decision to hire an engineer is yours, but there are typical situations under which you are advised to hire an engineer:

(a) Dam Design: If you need to build a storage dam, or if your intake dam is more than 1.5 metres high, an engineer should check the design and the foundations.

(b) Existing Dam: If you plan to use an existing dam to store water, an engineer should check the safety of the dam.

(c) Pipeline: If the head is greater than 30 m; if the length is longer than 300 m; or if the diameter is larger than 0.5 m an engineer should review your design for waterhammer, pipe strength, pipe supports and anchors. These limits are abribtrary and may not apply to all sites.

(d) Excavations: If you have to excavate into a steep or unstable looking side slope for an access road, pipeline or the powerhouse, an engineer should first check the stability of the slope.

(e) Safety If there are residences downstream of any part of the project and you will be changing the natural stream channel or leading water out of the natural channel (in a canal or pipeline), an engineer should check the safety of the project.

1.8 PROJECT COSTS

1.8.1 Capital Costs

Your project cost estimates will be very preliminary at this stage. You can use the cost curves in Figure 1-7 to 1-12 to find the cost of most of the components of your project.

You might want to buy used equipment or materials, such as:

- turbine
- pump - to be operated in reverse as a turbine
- generator
- other electrical equipment and wiring
- steel or plastic pipe

You can save 50 percent or more on the cost of new items. Ask turbine manufacturers if they have a used turbine or generator that would suit your project. Scrapyards and used equipment dealers are places to look for pumps, valves, electrical equipment, wire and pipe. Used equipment and materials are advertised in newspapers and trade journals and magazines.

No costs for used equipment are given in this Manual -- you will have to estimate costs based on your own enquiries. Beware, there are no guarantees on used equipment or materials, so make sure you know what to look for to check that the equipment or materials are in good condition.

When you have estimated the cost of each component, write it into the Summary of Project Costs, near the end of this section.

Site Preparation

Timber and brush will probably have to be cleared at the site of the intake, along the pipeline, at the powerhouse and along the transmission line. The storage reservoir, if you need one, will have to be cleared before you flood the area. A cat track or access road might have to be built to get construction materials and equipment to the intake, pipeline or powerhouse.

The cost of the work depends on the conditions at the site, therefore no cost curves are given to help you make an estimate. You could ask a local contractor, logger or cat owner for an approximate price.

Remember to include a cost -- even if it is only a guess -- for site preparation in your project cost estimate.

Storage Dam

You decided in Section 1.6.3 whether or not you needed a storage dam. At this stage you cannot make a reliable estimate of the cost of the dam. However, if you need to build a dam, include a cost for it in the Summary of Project Costs to remind yourselt that a dam could be a major part of the project cost. Use the larger of the following alternative costs:

(a) twice the cost of the intake weir (to be estimated next), or

(b) ten percent of the total civil, mechanical and electrical costs (to be calculated in the Summary of Project Costs at the end of this section).

Intake Weir

The intake weir could be built of concrete, rock gabions or rock-filled timber crib. A concrete dam would probably be the most expensive, a rock-filled dam the least expensive. Cost curves for concrete and gabion weirs only have been given in Figure 1.8. If you plan to build a timber-crib dam, you can make your own cost estimate or use the cost curve for the gabion weir, knowing that you are probably over estimating the cost of a timber-crib weir.

The curves in Figure 1.8 are for work done by a building contractor who pays union wages. Costs can be as low as 60 percent of the costs shown in Figure 1.8 if you do not hire a contractor and if the following conditions apply:

(a) you do most of the work yourself or pay wages at $12 per hour. and
(b) for the concrete dam you mix concrete at the site, or
(c) for the gabion dam you do not have to pay for delivery of rocks for the gabions because there are rocks close to the site.

To find the cost of the weir using Figure 1.8:

(a) decide on the type of weir you will build,
(b) decide on the height of the weir,
(c) select the height on the vertical axis, then read off the cost per metre of weir on the horizontal axis,
(d) estimate the length of weir, and
(e) calculate the cost using the formula cost of weir = cost/m x length (m).

Example:

Concrete weir 1.5 m high, 6 m long, built by contractor.

Using Figure 1-8:

	Example	Your Values
Weir height	1.5 m	.... m
Weir length (a)	6.0 m	.... m
Cost per length of weir (b) ..	210 $/m	.... $/m
Cost of weir (a x b)	1260 $	.... $

Pipeline Intake

In Figure 1.9 cost curves are shown for a free-standing intake for a gabion or rock-filled timber weir, and for an intake for a concrete weir where the backwall of the intake would be part of the concrete dam.

To find the cost of the intake using Figure 1.9

(a) select the pipeline diameter,
(b) find the submergence required for this pipe diameter, using the bottom graph,
(c) estimate the actual height of the intake (the headpond behind the intake weir might be deeper than the minimum height required in Item 2 above),
(d) find the cost of the intake for the correct pipeline diameter, using the top graph, and
(e) add the cost of the trashrack from the middle graph.

Example:

Pipe diameter (Section 1.5.3. "Pipeline")	D = 410 mm
Submergence required (bottom graph Figure 1.9)	= 1.0 m
Height of intake = height of weir (1.5 m) + 0.5 m	= 2.0 m
Cost of intake (using 500 mm pipe diameter on Figure 1.9)	$670
Cost of trashrack for 400 mm pipe (middle graph figure 1.9)	$180
Total Cost of Intake	$850

Pipeline

Before you can calculate the cost of the pipeline, you must first make a sketch of the pipeline route (as shown in Sketch (A) in Figure 1.10) and mark a few ground elevations and lengths along the pipeline to define the profile. For example, EL. 10 m, EL. 20 m, EL. 30 m; and L_1, L_2, L_3. This will enable you to estimate the head on various sections of the pipeline, (as shown in Sketch (B)) and to choose the correct cost for each section: this applies to polyethylene plastic pipes only.

In the table on Figure 1.10, Column #1 shows a Pipe Classification which corresponds to a range of Gross Heads (or pressure heads) in Column #2. Each classification of pipe can withstand a pressure head equal to the maximum in the range in Column #2, for example, "A" pipe can withstand a gross head up to 13.7 m, and "B" pipe a gross head of 18.3 m. This classification is for polyethylene pipe only; steel pipe is strong enough to withstand a gross head in excess of 150 m.

For costing polyethylene pipe, mark off the maximum gross head in each classification on your sketch of the pipeline starting from the intake, as in Sketch (B), Figure 1.10. Then measure the length of each classification of pipe, for example LA, LB, LC in Sketch (B).

For each classification, read from the table on Figure 1.10 the cost per metre of pipe under the appropriate pipe diameter; multiply that unit cost by the length for that classification to give the cost of that section of pipe.

Example:

Pipe diameter - 410 mm inside diameter. Assume a nominal outside diameter of 450 mm.

Draw a table as shown below. The lengths LA, LB etc. are taken from your sketch, similar to Figure 1.10, Sketch (B). The unit costs of pipe per metre are taken from the table on Figure 1.10. We will assume a 500 mm pipe in this example, but you could interpolate the cost for a 450 mm diameter pipe between the costs for pipes of 315 mm and 500 mm.

Pipe Classification	Length m	Unit Cost $/m	Cost of Section $
A	LA = 50	155	7750
B	LB = 10	205	2050
C	LC = 20	265	5300
D	LD = 13	324	4212
E	LE = 13	518	6734
F	LF = 10	518	5180
Total Cost of Pipeline			$31226

Note that the unit cost of 500 mm diameter pipe in Class E is below the heavy line in the table, indicating that it is steel pipe. A polyethylene pipe of that diameter cannot withstand a gross head greater than 30.5 m (classification D).

Add the cost of a valve, from the table on Figure 1.10, to get the total cost of the pipeline.

Powerhouse

Figure 1.11 shows cost curves for the powerhouse sub-structure (concrete foundations and floor) and superstructure (wood or prefabricated metal).

For the sub-structure cost you need the rated output of your hydro plant in kW, which you should already have estimated. Use the top graph on Figure 1.11 to find the sub-structure cost.

The superstructure floor area depends on the physical dimensions of the turbine and generator. The size is related to the penstock diameter. Use the bottom graph on Figure 1.11 to find the cost of the superstructure for the penstock size and type of turbine you have selected.

Add the costs of the sub-structure and superstructure to get the total powerhouse cost.

Turbine, Generator and Electrical Equipment

Use Figure 1.12 to estimate the cost of the turbine, generator and electrical equipment in the powerhouse. You need to know the gross head (from Section 1.4.2) and the energy output hydro plant in kW. To find the cost of the equipment, find the head on the vertical axis, draw a line horizontally to intersect the diagonal line with the correct range of plant output (you can interpolate between these lines), then draw a vertical line down to the horizontal axis. Read the cost (in $/kW) of the equipment and multiply by the plant output in kW.

The cost lines on Figure 1.12 were derived from manufacturers prices and show average costs. They should be used only for initial estimates, since the prices you actually pay for the turbine, generator and other electrical equipment could be as much as 40 percent less than the costs given on Figure 1.12. You will generally get the quality you pay for: low-priced turbines will probably be made of cheaper materials and will probably require more repair than higher-priced turbines.

A very small turbine-generator unit (1.0 - 1.5 kW) with batteries and a battery-charger might be suitable for lighting and a few appliances in a small, well-insulated house or summer cabin. The cost of turbine, generator, batteries, and inverter would be about

1.0 kW	$ 9000
1.5 kW	$13000

Remember, if you will be converting from existing oil or propane heating to electric heating, there will be additional costs for electric heaters and wiring at your house, lodge, camp, or mill. These additional costs are not covered in this manual.

Transmission Lines and Cables

Use the table below to estimate the cost of transmission lines or cables running from the hydro plant to the load. Refer to Chapter 4 for a discussion of voltages and different types and sizes of cable you should use.

Wood Pole Transmission Line 3-phase, 2.4 kV, up to 250 kW:	$17000/km
High Voltage Buried Cable single-phase, up to 85 kW:	$15000/km

Tailrace Channel

The tailrace channel is usually a minor cost item, however, a cost figure should be included in the estimate. A cost curve cannot be prepared for the tailrace channel because the channel dimensions depend entirely on the site. Make your own estimate for this item or ask for an estimate from the person who advised you on the clearing and access costs.

Contingencies

Contingencies are unexpected costs.

The cost curves in Figure 1.8 to 1.12 were drawn using cost estimates from manufacturers, suppliers and contractors, and using costs of projects recently built. However, the cost of your project will probably be more than you have estimated so far: that's the way things usually turn out. Some reasons for this:

1. The project you build might be more complicated than the one you have planned.
2. The dimensions of the project you build might be larger than you have estimated.
3. The cost curves do not include every possible expense.
4. Unexpected problems will probably arise during construction.
5. Add more if the project has accessability problems.

To avoid surprises, be conservative. Add a contingency item to your cost estimate, as follows:

1. Add 15 percent if you think your project will be easy to build, and you think you have included everything.
2. Add 25 percent if you think your project might be more complicated than most, or if you think you might have underestimated some of the dimensions such as, length of penstock or transmission line.

Engineering Costs

You have probably decided whether or not you will hire an engineer. This section suggests costs to expect for engineering services.

Even if you want to do all the planning yourself, you should still provide for the cost of expert advice you might need unexpectedly.

If you do hire an engineer, here are some guidelines to help you estimate the costs. For advice on specific problems, or the design of certain structures, engineers normally charge hourly or daily rates for their services:

$30 to $70 per hour;
$200 to $500 per day.

For a visit to the site, an engineer would expect to be paid, probably at a reduced rate, while he was travelling, and he would want to be paid for reasonable expenses. Generally, a self-employed engineer will charge less than a firm of engineers which has to cover higher overheads.

If you have to borrow money to build the project, the banks, or other investor, may ask for a feasibility study report to show:

(a) the availability of a site for your project,
(b) the availability of sufficient flow and head to produce the power and energy you need,
(c) an estimate of the costs of the project, and
(d) a simple financial analysis showing loan repayments and other facts the bank or investor might require.

For a feasibility study and report, expect to pay between a minimum of $2000 (that would be a nominal fee) and, $7000 to $15000 for a project of 50 kW to 250 kW.

For a feasibility study report, and the complete design and construction supervision of a project, expect to pay 5 to 15 percent of the project cost, or a minimum of $8000.

Remember, before you hire an engineer or other expert, ask for an estimate of the cost and a letter detailing exactly what the engineer will do for the money.

Summary of Project Costs

Make a list of all the costs that apply to your project.

	Example Costs	Your Project Costs
Clearing and Access	$ 1000	$................
Storage Dam	$ 0	$................
Intake	$ 1300	$................
Pipeline	$ 31900	$................
Turbine, Generator, Electrical Equipment	$ 45500	$................
Powerhouse	$ 10700	$................
Transmission	$ 8000	$................
TOTAL COST OF STRUCTURES AND EQUIPMENT (a)	$ 98400	$................
Engineering	$ 7000	$................
Contingencies (15% of (a))	$ 15000	$................
TOTAL PROJECT COST	$120400	$
	======	==============

Cost per kW

To check the cost of your project, compare its "Cost per kW" with other plants. To get the cost in $/kW, divide the total project cost by the design capacity of the plant (from Section 1.6.2).

	Example	Your Figures
Total Project Cost (from Summary of Project Costs)	$120400	$...........
Design Capacity (from Section 1.6.2)	35 kW	.... kW
Cost per kW	3440 $/kW	.... $/kW

The cost per kW should be within the range of $2000 to $5000 per kW.

If your figure is around $2000 per kW you have a good project. If the figure is around $5000 per kW, you still might have a project that is cheaper than an alternative power source, such as diesel. You will know this when you have calculated the annual cost of your plant in Section 1.8.2.

Degree of Confidence in Project Cost Estimate

Only an approximation of the actual project cost can be expected at this stage in the planning process, when the structures have yet to be designed and the sites have yet to be carefully examined. Nevertheless, the actual project cost will probably be within 25 percent of your estimate.

1.8.2 Annual Costs

You should be aware of the annual cost of energy, including loan payments and maintenance and repair costs, of your hydro project. You might want to compare that cost with the cost of energy from a diesel generator or from a nearby transmission line.

Loan Payments

Decide how much you will have to borrow to cover the total project cost, then calculate your annual payments (capital and interest) using a Capital Cost Recovery Factor (CRF) from Table 1.2.

Example:

Assume you want to repay a loan in 10 years, and the interest rate is 10 percent.

	Example	Your Values
- Total Project Cost	$120400	$ ....
- Equity Available for Project	$ 30400	$ ....
- Loan Required (a)	$ 90000	$ ....
From Table 1.2:		
For: n = ...	10 years	.... years
i = ...	10%	.... %
Find: CRF = ...	0.163	....
Annual Loan Payment:		
(CRF) x (a) = ...	0.163 x 90000	...... x ......
=	$14670	$ ....

Maintenance and Repair Costs

Maintenance and repair costs include maintaining the intake, dam, pipeline, powerhouse and the mechanical and electrical equipment. The maintenance work that should be done is discussed in Chapter 3. However, for this initial estimate of annual costs, use 2% of the Total Project Cost, or $2000 minimum annual maintenance cost.

Total Annual Costs

Add the annual loan payments and the annual maintenance and repair costs to get the total annual cost. Divide this by the estimated annual energy output (from Section 1.6.4) to get the cost per kW.h.

Example:

	Example	Your Values
- Annual Loan Payment	$ 14670	$ ....
- Annual Maintenance & Repair Costs	$ 2400	$ ....
Total Annual Costs (a)	$ 17070	$ ....
- Annual Energy Output (from Section 1.6.4)	(b) 245000 kW.h	.... kW.h
- Cost per kW.h =	(a) x 100/(b) = 7.0 c/kW.h	...... c/kW.h

In the next section you will compare the cost per kW.h with the cost of alternative sources of energy.

1.9 PROJECT WORTH

You now have information that will help you decide whether to continue with a more detailed exploration of the site, or whether to drop the project and look for another way of getting power.

First it will be helpful to answer these three questions:

1. Are the power and energy from your hydro project sufficient to meet your load at all times of the year?

2. Is the total Project Cost acceptable to you, that is, can you borrow enough money to build the project?

3. Is the cost of energy from your hydro project

   (a) less than the cost of energy (including the transmission line) from a utility, (assuming there is a power line close enough to your property) and/or
   (b) less than the cost of energy from a diesel plant, (assuming you already have one, or that this would be your alternative source of electricity)?

If the answers to these questions are "yes", you're ready to continue work on the project.

If there is not enough energy from the stream, consider the following:

1. Can you do without energy for a short period when the stream is low?
2. Can you get more head out of the stream by moving the intake upstream, or the powerhouse downstream?
3. Can you get some storage in the stream to help you through the dry periods?
4. Would automatic load management equipment reduce your peak load more than you have already assumed in Section 1.2?

If the answer to even one of these questions is "yes" or "maybe" and the cost of energy from your hydro projet is less than the costs from diesel or a utility, you could continue the project, by gathering more data in Chapter 2 and reassessing the project in Chapter 3.

If you have a diesel plant, could you meet your load year-round if you used the diesel for a short period (a month) each year or maybe even one hour a day? The economics of using diesel to supplement hydro are treated in Chapter 3. For now, you will have to judge if supplemental power is a reasonable alternative to consider.

In summary, if you think your project will be economic and will provide the energy you need, continue planning. If you are "not sure", you are still advised to continue planning until you have a definite "yes" or "no". There are other places in this manual where you will be asked to reconsider your decision to build or not.

1.10 CONTINUED PLANNING

You should decide if you are going to continue to do the planning yourself or hire an engineer. The rest of this manual is designed for the person doing his/her own planning and/or building, however it will also tell those who are hiring an engineer, what the engineer will do.

1.10.1 Water Licence

By now you will know where you want to build your project.

Write to the nearest office of the Water Management Branch of the Provincial Ministry of the Environment, and apply for a water licence. (Addresses of the Water Management Branch Offices are given in Appendix B at the end of the book.)

Give the following details:

(a) the name of the creek or river on which you propose to build the project,
(b) the area of the drainage basin above the intake (measure this from a large scale map),
(c) the approximate locations of the intake, dam, pipeline, powerhouse all plotted on a sketch,
(d) the power output you expect from your project,
(e) the head you expect to use, and
(f) the flow you expect to use for power.

Ask:

(a) if there is any streamflow data for your stream,
(b) if there is a need to consult an engineer for any part of your project, and
(c) if there are any fish and wildlife restrictions to using your stream for hydro power.

The responsibilities of the Water Management Branch with respect to a small hydro project are:

(a) to ensure that previous water rights are not adversely affected by your project,
(b) to ensure that your project will meet environmental standards,
(c) to ensure public safety, and
(d) to collect water rental fees

1.11 Project Data Summary

If you have not already done so, summarize on Table 1.3 the data you have calculated, measured or estimated on in Chapter 1.

TABLE 1.1

TYPICAL HOUSE & CAMP LOADS

(With Automatic Load Management*)

		RANGE OF MAXIMUM LOADS	
		SUMMER kW	WINTER kW
1)	CABIN		
	Electric light, kitchen appliances, washer, dryer, space heating, fridge, freezer, hot water, water pump, skill saw; no electric stove.	1.5 - 4.0	3.0 - 5.0
	HOUSE - 2 BEDROOM		
2A)	Same equipment as in 1, with non-hydroelectric back-up (eg. propane, oil or diesel) for space heating.	4.0 - 5.0	5.0 - 6.0
2B)	Same equipment as in 1, without back-up for space heating.	4.0 - 5.0	7.0 - 9.0
2C)	Same equipment as in 2B, plus electric stove.	11.0 - 13.0	12.0 - 14.0
	HOUSE - 3-4 BEDROOM		
3A)	Same equipment as in 2A, plus hot-tub (N.B. back-up for heating).	4.0 - 5.0	5.0 - 6.0
3B)	Same equipment as in 3A, without back-up for heating.	4.0 - 5.0	8.0 - 13.0
3C)	Same as in 3B, plus electric stove or swimming pool.	13.0 - 15.0	14.0 - 15.0
	WORK CAMP - 20-200 PERSONS	SUMMER OR WINTER	
4A)	Bunkhouse, recreation room, dining room, office, kitchen - no electric cooking stoves (propane stoves).	1.0 - 1.5 kW/person	
4B)	Semi-permanent, more luxurious than 4A) (eg. one bathroom to two bedrooms) - no electric cooking stoves.	1.7 - 2.2 kW/person	

* Maximum loads during peak demand, or maximum average 24 hour load assuming automatic load management - whichever is larger.

TABLE 1.2

CAPITAL COST RECOVERY FACTORS

(The amount to be paid per year to redeem a loan of $1 over n years.)

n	9%	10%	12%	15%
1	1.0900	1.100	1.1199	1.1500
2	0.5685	0.5762	0.5917	0.6151
3	0.3951	0.4021	0.4164	0.4380
4	0.3087	0.3155	0.3292	0.3503
5	0.2571	0.2638	0.2774	0.2983
6	0.2229	0.2296	0.2432	0.2642
7	0.1987	0.2054	0.2191	0.2404
8	0.1807	0.1874	0.2013	0.2229
9	0.1668	0.1736	0.1877	0.2096
10	0.1558	0.1627	0.1770	0.1993
11	0.1469	0.1540	0.1684	0.1911
12	0.1397	0.1468	0.1614	0.1845
13	0.1336	0.1408	0.1557	0.1791
14	0.1284	0.1357	0.1509	0.1747
15	0.1241	0.1315	0.1468	0.1710

TABLE 1.3

PROJECT DATA SUMMARY - CHAPTER 1

LOAD: (From Section 1.2)

Present: Summer Peak (month) .... kW

Winter Peak (month) .... kW

Expected: Summer Peak (month) .... kW

Winter Peak (month) .... kW

STREAMFLOW: (From Section 1.4.1)

Minimum Flow Measured .... m^3/s Date ....

Maximum Flow Measured .... m^3/s Date ....

Estimated Lowest Expected Flow (Q_{min}) ....

HEAD: (From Section 1.4.2)

Measured or Estimated Gross Head (Hg) .... m

AVAILABLE POWER AND ENERGY: (From Section 1.6)

Firm Power (P_{firm}) .... kW

Average Annual Energy (E_{annual}) .... kW

Design Capacity (P_{design}) .... kW

PROJECT DIMENSIONS: (From Section 1.5)

Intake Weir: Length .... m Maximum Height .... m

Storage Dam: Is one needed? ....

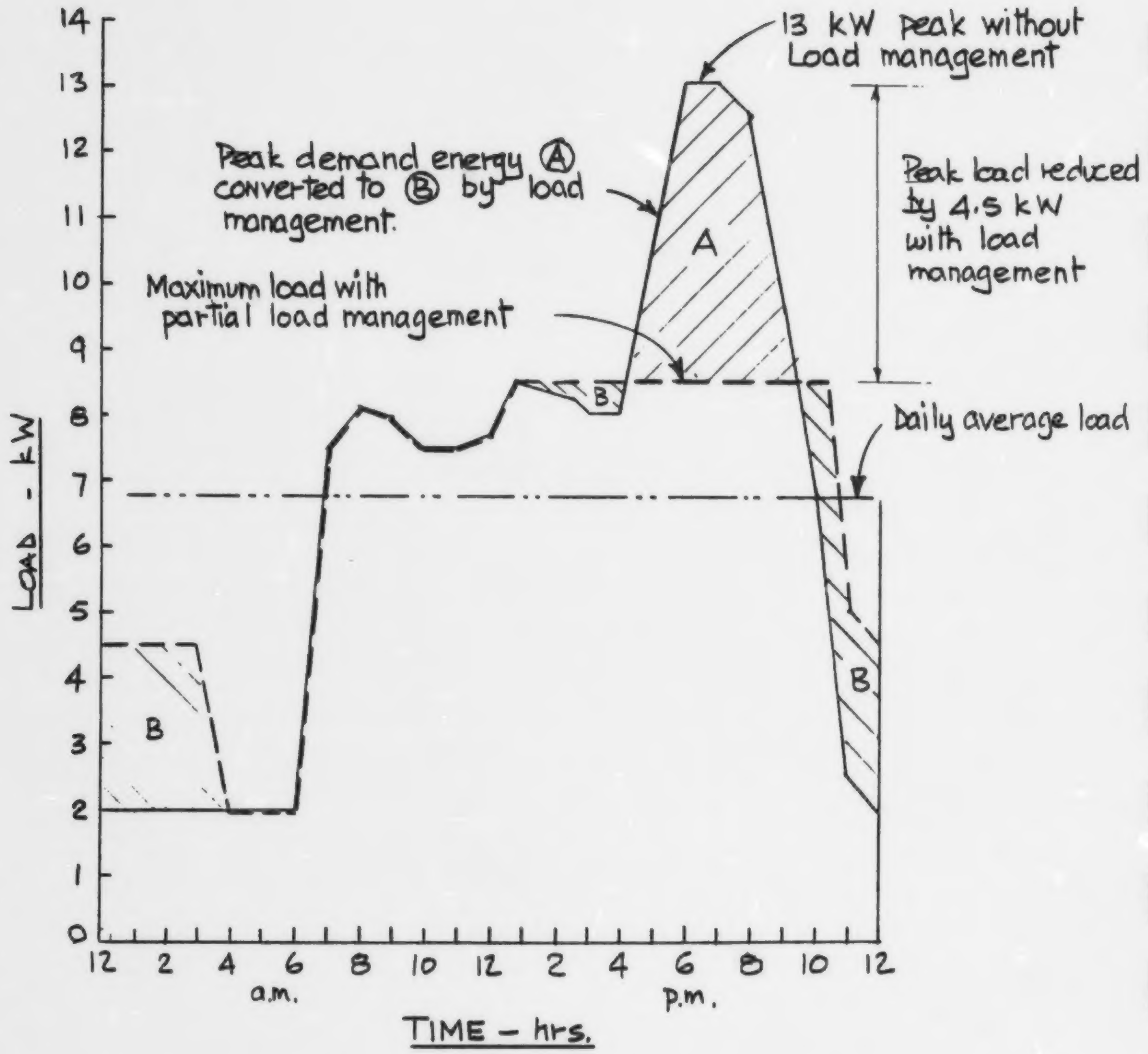
Existing Dam: Is there one? ....

Pipeline: Length .... m Diameter .... mm
(Section 1.4.3)

Powerhouse: Length .... m Width .... m

Transmission Line: Length .... km

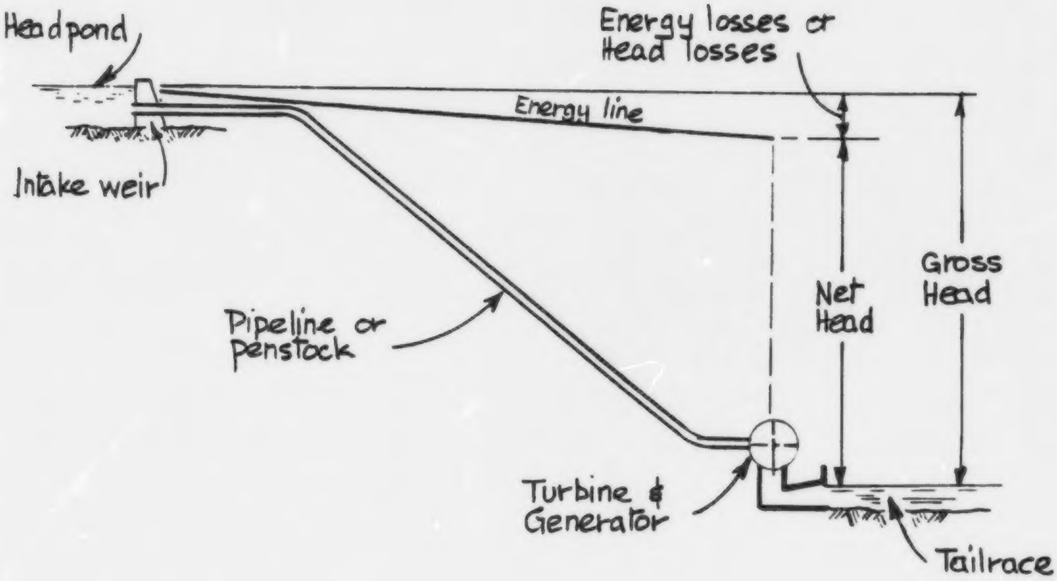
Drainage Basin: Area .... km^2



Load curves for a 3-bedroom house in winter:
—— uncontrolled load curve
— — — load curve with partial load management

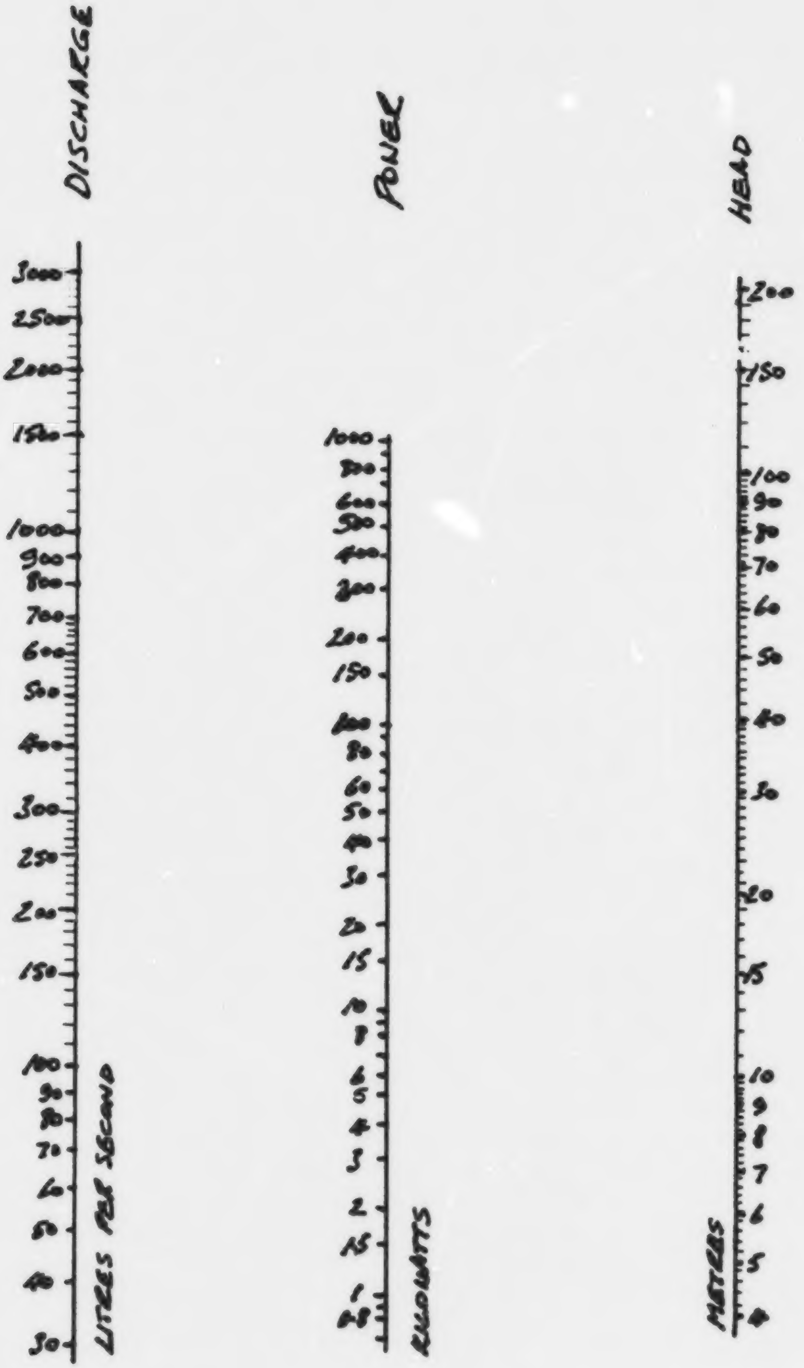
TYPICAL DAILY DOMESTIC LOAD CURVE

FIGURE 1.1


Headpond
Energy losses or Head losses
Energy line
Intake weir
Gross Head
Net Head
Pipeline or penstock
Turbine & Generator
Tailrace

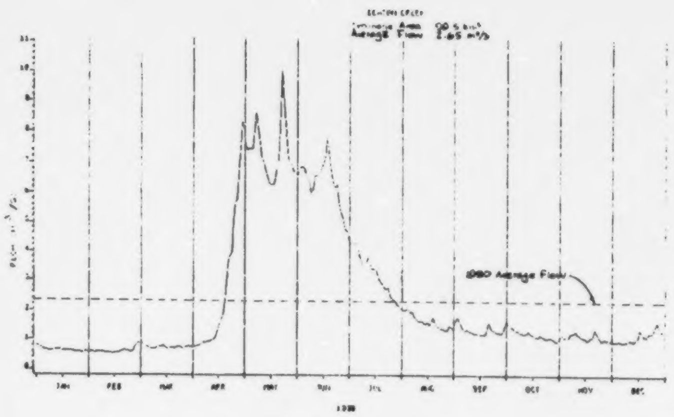
DEFINITION OF HEAD

FIGURE 1·2

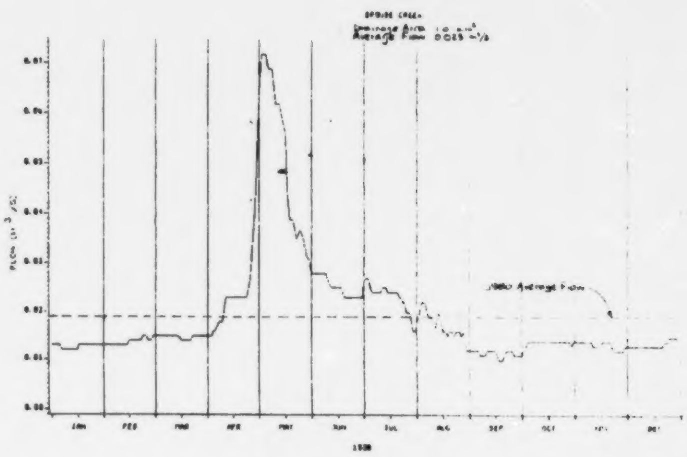


Read Section 1.3.1 in the text to find out how to use this nomograph.

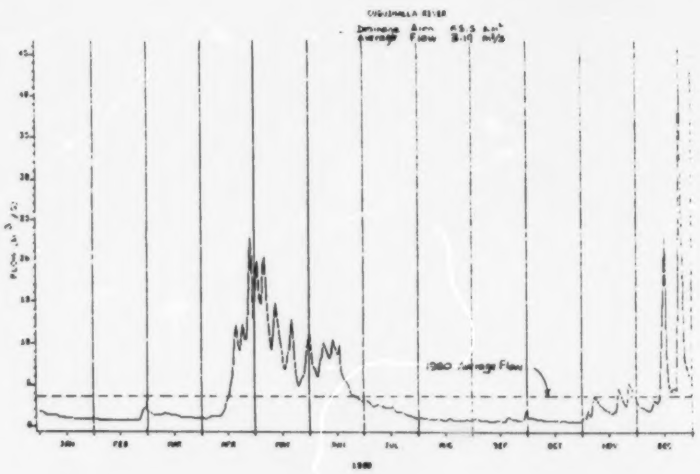
FIG 1·3 DISCHARGE - HEAD - POWER NOMOGRAPH



SOUTHEAST INTERIOR



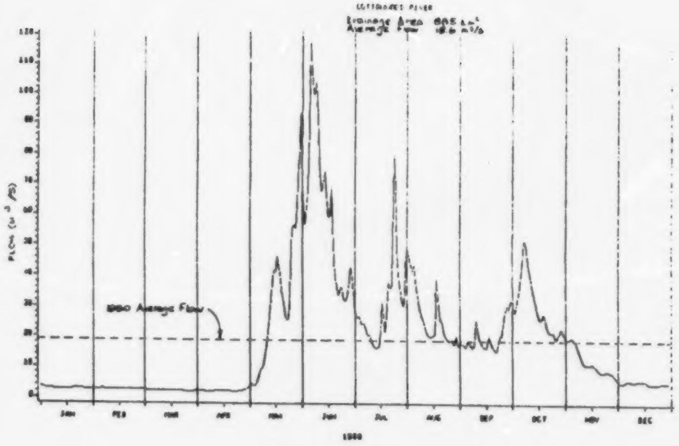
SOUTHEAST INTERIOR



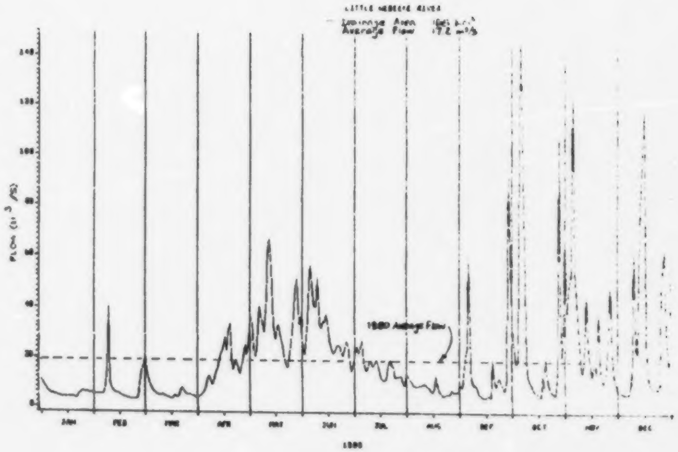
SOUTHEAST INTERIOR

LOCATION PLAN

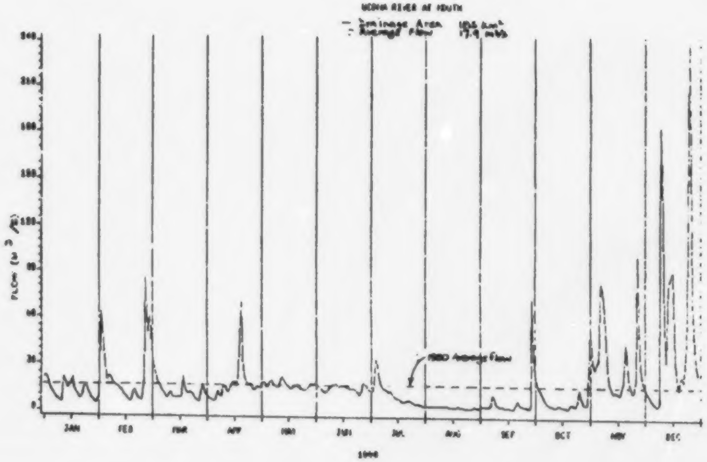
FIGURE 1.4 A



NORTH INTERIOR

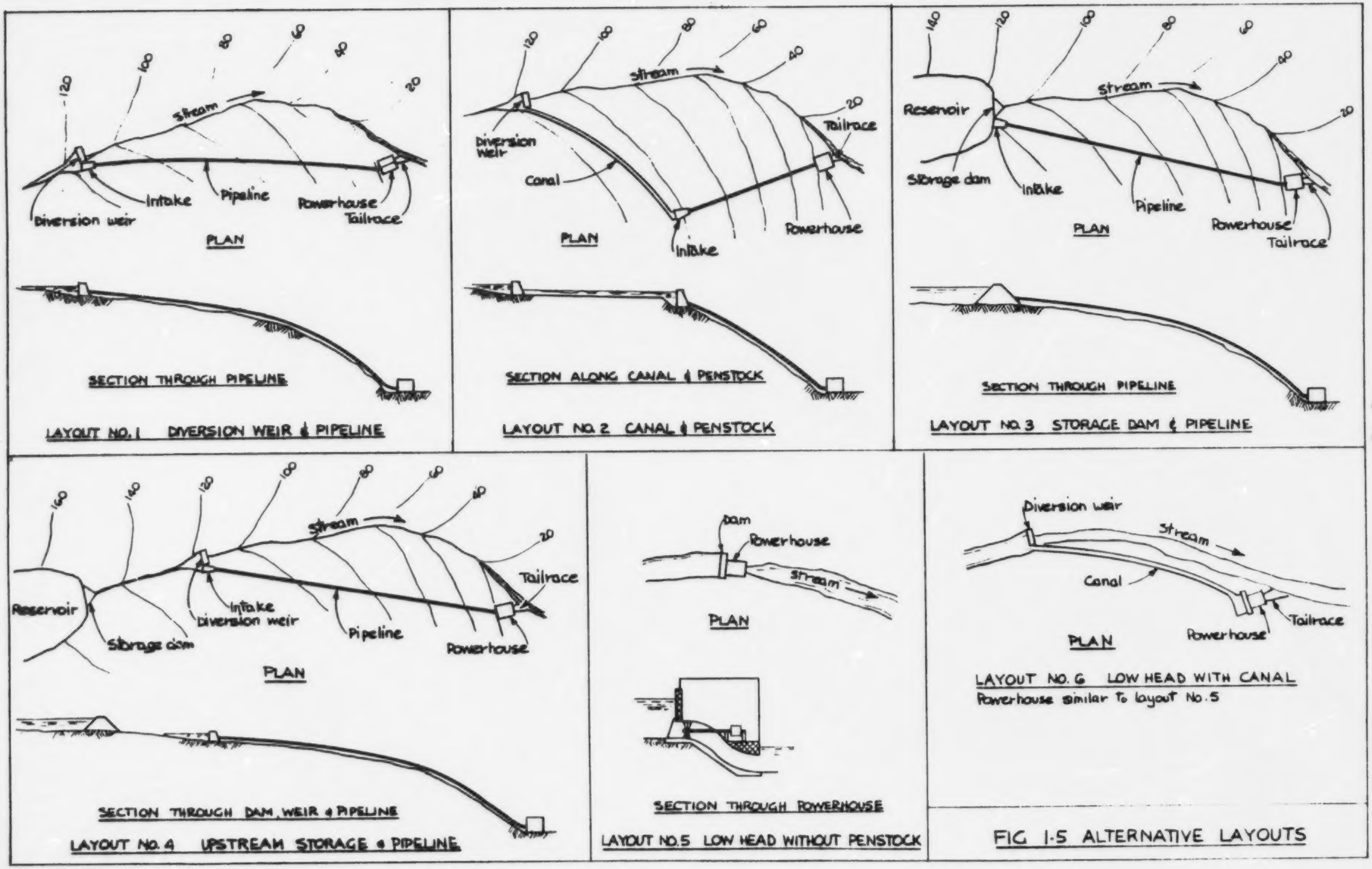


MAINLAND COAST



VANCOUVER ISLAND

FIGURE 4 B


120
100
80
60
40
20
stream
Diversion weir
Intake
Pipeline
Powerhouse
Tailrace
PLAN
SECTION THROUGH PIPELINE
120
100
80
60
40
20
stream
Diversion Weir
Canal
Intake
Powerhouse
Tailrace
PLAN
SECTION ALONG CANAL & PENSTOCK
140
120
100
80
60
40
20
Resenoir
Storage dam
Intake
stream
Pipeline
Powerhouse
Tailrace
PLAN
SECTION THROUGH PIPELINE
160
140
120
100
80
60
40
20
Resenoir
Storage dam
Intake
Diversion weir
stream
Pipeline
Powerhouse
Tailrace
PLAN
SECTION THROUGH DAM, WEIR & PIPELINE
Dam
Powerhouse
stream
PLAN
SECTION THROUGH POWERHOUSE
Diversion weir
stream
Canal
Powerhouse
Tailrace
PLAN

LAYOUT NO. 1 DIVERSION WEIR & PIPELINE

LAYOUT NO. 2 CANAL & PENSTOCK

LAYOUT NO. 3 STORAGE DAM & PIPELINE

LAYOUT NO. 4 UPSTREAM STORAGE & PIPELINE

LAYOUT NO. 5 LOW HEAD WITHOUT PENSTOCK

LAYOUT NO. 6 LOW HEAD WITH CANAL
Powerhouse similar to layout No. 5

FIG 1.5 ALTERNATIVE LAYOUTS

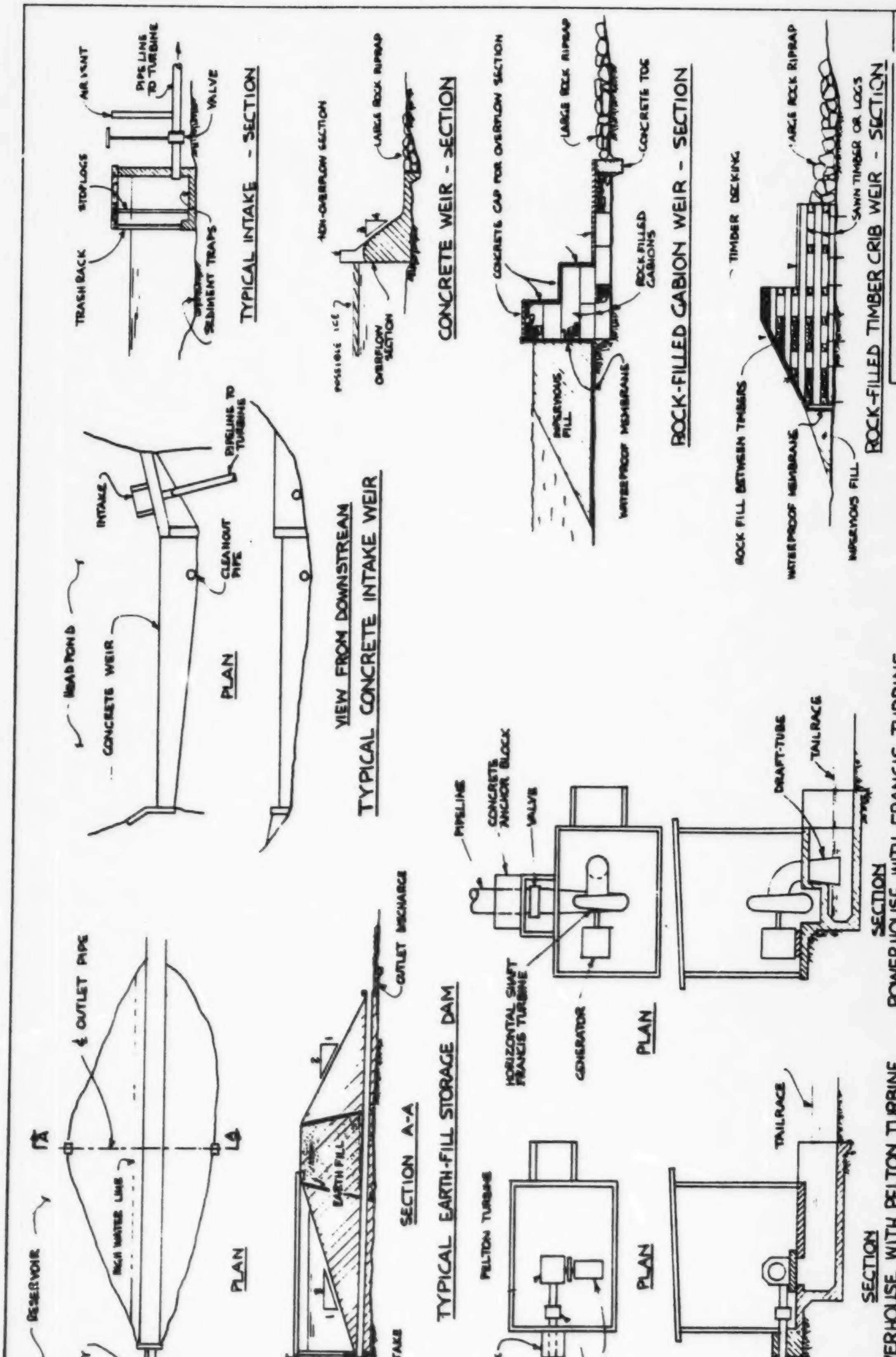
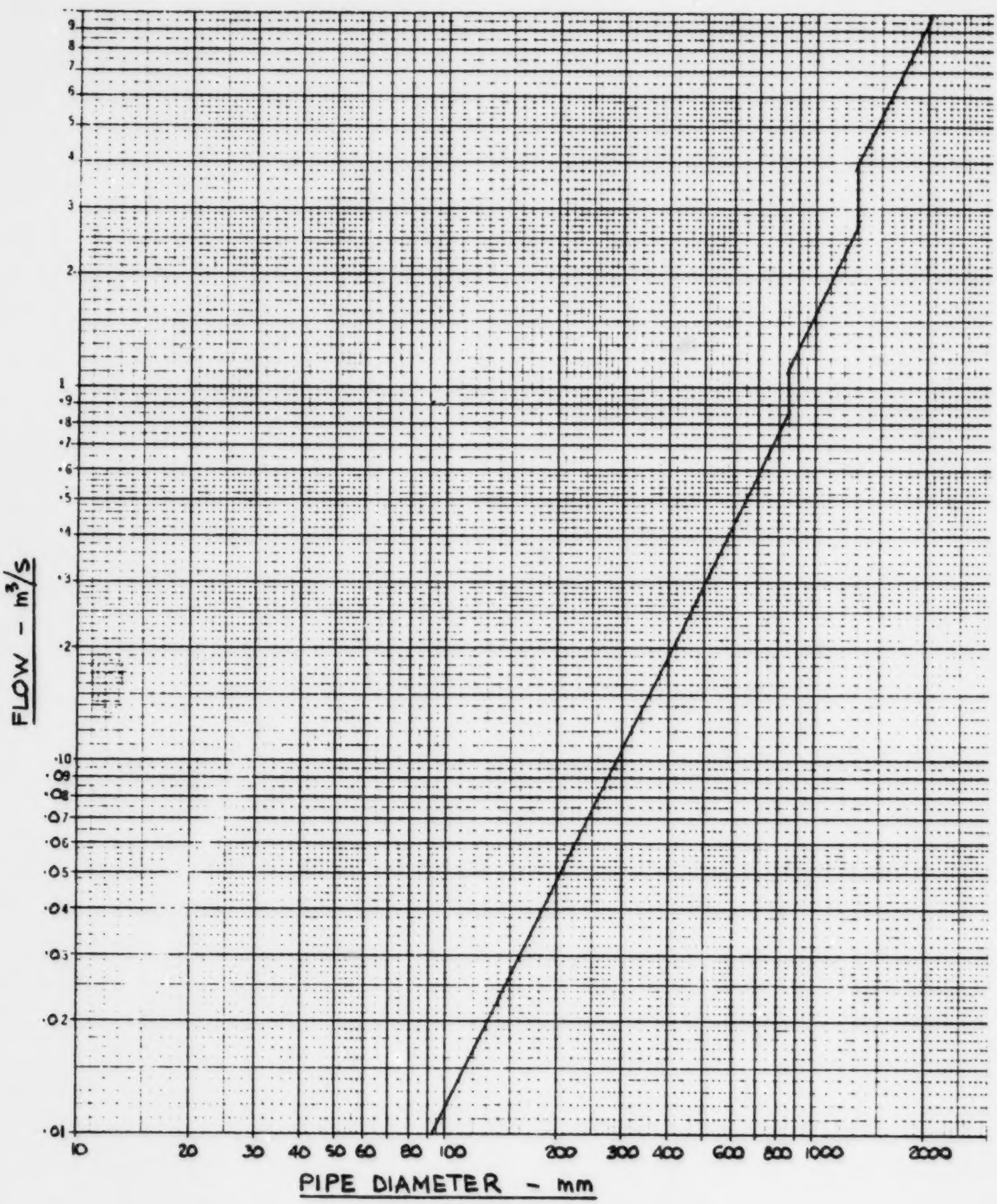

RESERVOIR
SPILLWAY
HIGH WATER LINE
℄ OUTLET PIPE
A
A
PLAN
OUTLET INTAKE
EARTH FILL
OUTLET DISCHARGE
SECTION A-A
TYPICAL EARTH-FILL STORAGE DAM
CONCRETE ANCHOR BLOCK
PIPELINE
VALVE
GENERATOR
PELTON TURBINE
PLAN
TAILRACE
SECTION
POWERHOUSE WITH PELTON TURBINE
HEADPOND
CONCRETE WEIR
INTAKE
PIPELINE TO TURBINE
CLEANOUT PIPE
PLAN
VIEW FROM DOWNSTREAM
TYPICAL CONCRETE INTAKE WEIR
PIPELINE
CONCRETE ANCHOR BLOCK
VALVE
HORIZONTAL SHAFT FRANCIS TURBINE
GENERATOR
PLAN
DRAFT-TUBE
TAILRACE
SECTION
POWERHOUSE WITH FRANCIS TURBINE
TRASHRACK
STOPLOGS
AIR VENT
PIPE LINE TO TURBINE
VALVE
SEDIMENT TRAPS
TYPICAL INTAKE - SECTION
POSSIBLE ICE
OVERFLOW SECTION
NON-OVERFLOW SECTION
LARGE ROCK RIPRAP
CONCRETE WEIR - SECTION
CONCRETE CAP FOR OVERFLOW SECTION
LARGE ROCK RIPRAP
ROCK-FILLED GABIONS
CONCRETE TOE
IMPERVIOUS FILL
WATERPROOF MEMBRANE
ROCK-FILLED GABION WEIR - SECTION
TIMBER DECKING
LARGE ROCK RIPRAP
ROCK FILL BETWEEN TIMBERS
WATERPROOF MEMBRANE
IMPERVIOUS FILL
SAWN TIMBER OR LOGS
ROCK-FILLED TIMBER CRIB WEIR - SECTION

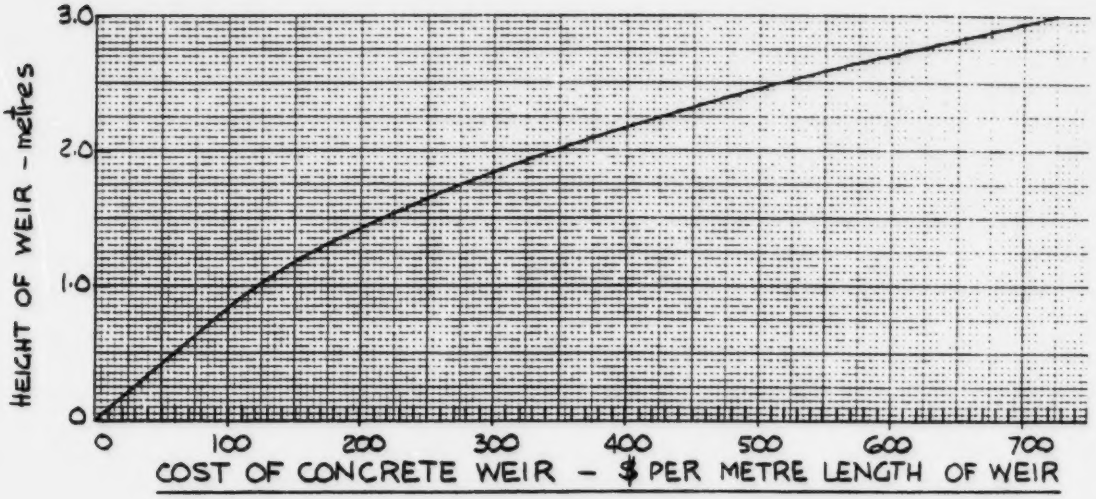
FIG 1·6 TYPICAL STRUCTURES

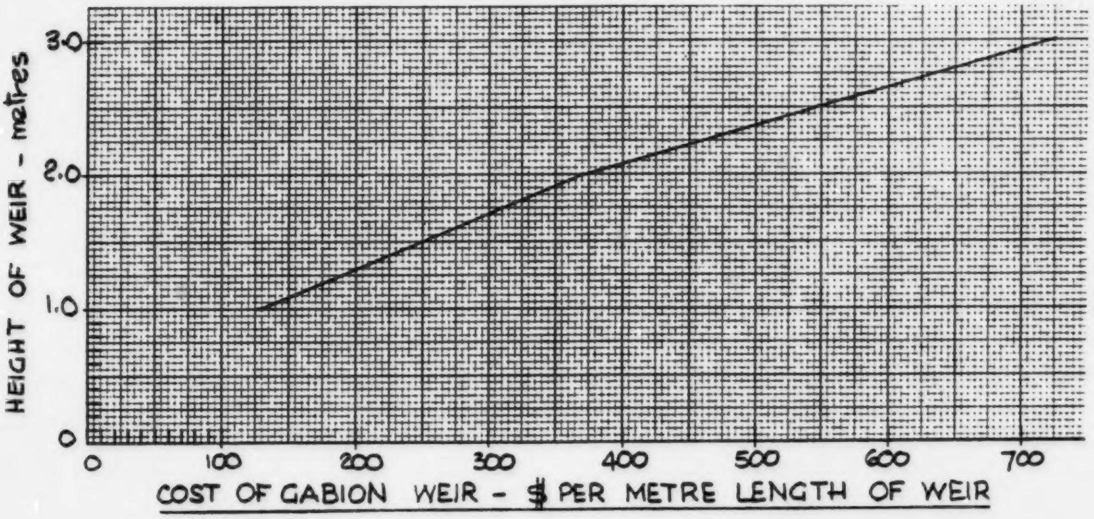


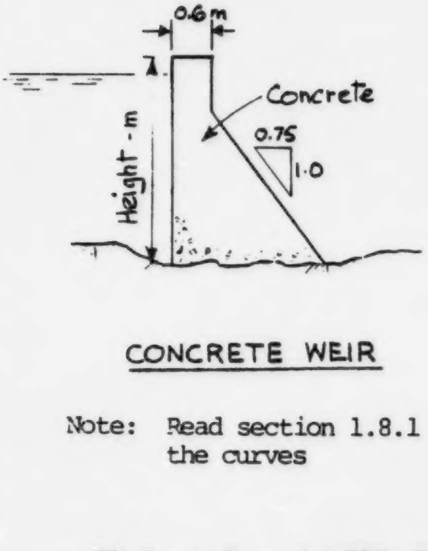
Note: Flow velocity in pipes is as follows:

Pipe diameter	Velocity
100 mm - 850 mm	1.5 m/s
850 mm - 1300 mm	2.0 m/s
1300 mm - 2000 mm	5.0 m/s

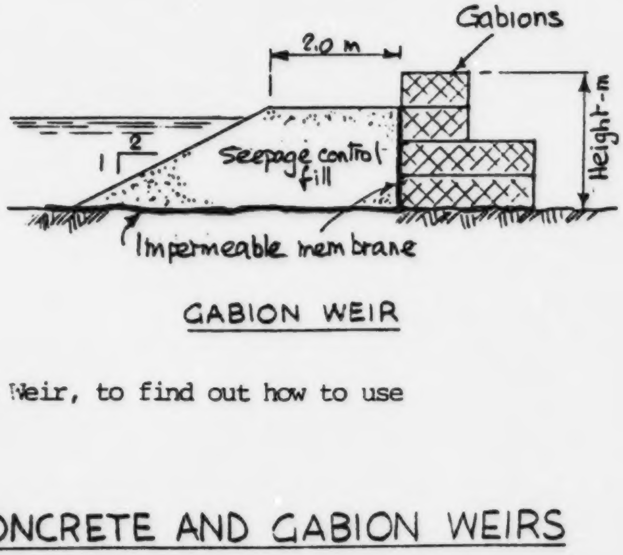
FIG 1·7 PIPE DIAMETER VS FLOW






0.6m
Concrete
0.75
1.0
Height - m

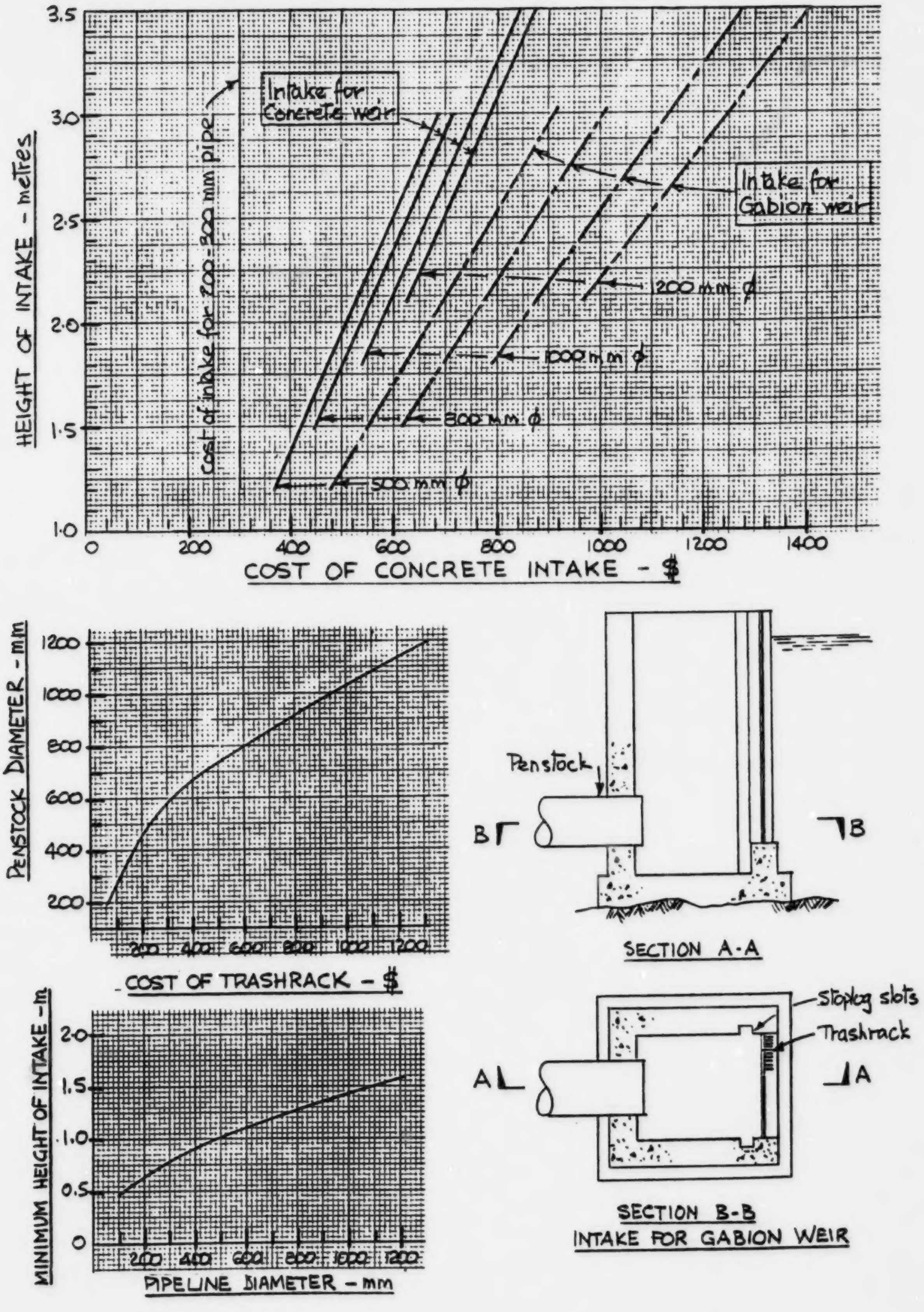
CONCRETE WEIR


Gabions
2.0 m
Height - m
2
1
Seepage control fill
Impermeable membrane

GABION WEIR

Note: Read section 1.8.1 Intake Weir, to find out how to use the curves

FIG 1·8 COST OF CONCRETE AND GABION WEIRS

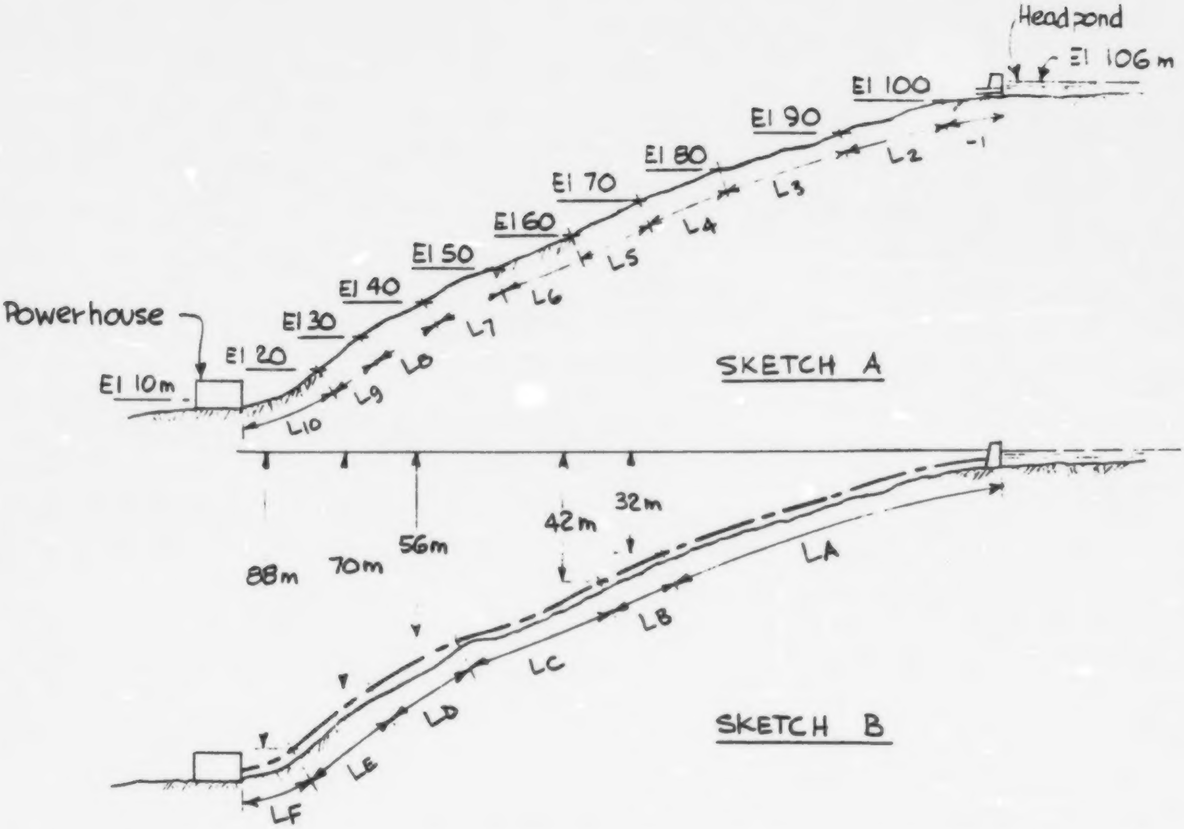


SECTION A-A

SECTION B-B
INTAKE FOR GABION WEIR

FIG 1·9 INTAKE COST

Note: Read section 1.8.1 Pipeline Intake to find out how to use these curves


Headpond
El 106m
El 100
El 90
El 80
El 70
El 60
El 50
El 40
El 30
El 20
El 10m
Powerhouse
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
SKETCH A
88m
70m
56m
42m
32m
LA
LB
LC
LD
LE
LF
SKETCH B

PIPE CLASS	GROSS HEAD-m	NOMINAL PIPE DIAMETER - mm (1)						
		200	315	500	800	1000	1200	
	FROM - TO	COST OF PIPE PER METRE - $/m						
A	0 - 31·6	25	64	155	405	625	910	(2)
B	31·6 - 42·2	35	80	205	530	1030	1235	
C	42·2 - 56·2	43	106	265	683	1030	1235	
D	56·2 - 70·3	52	128	324	830	1030	1235	
E	70·3 - 87·8	62	154	518	830	1030	1235	
F	87·8 - 112·5	78	190	518	830	1030	1235	
G	112·5 - 140·6	92	220	518	830	1030	1235	
H	140·6 - 150·0	170	330	518	830	1030	1235	
COST OF VALVE - $		240	410	2,630	7,740	10,400	17,700	

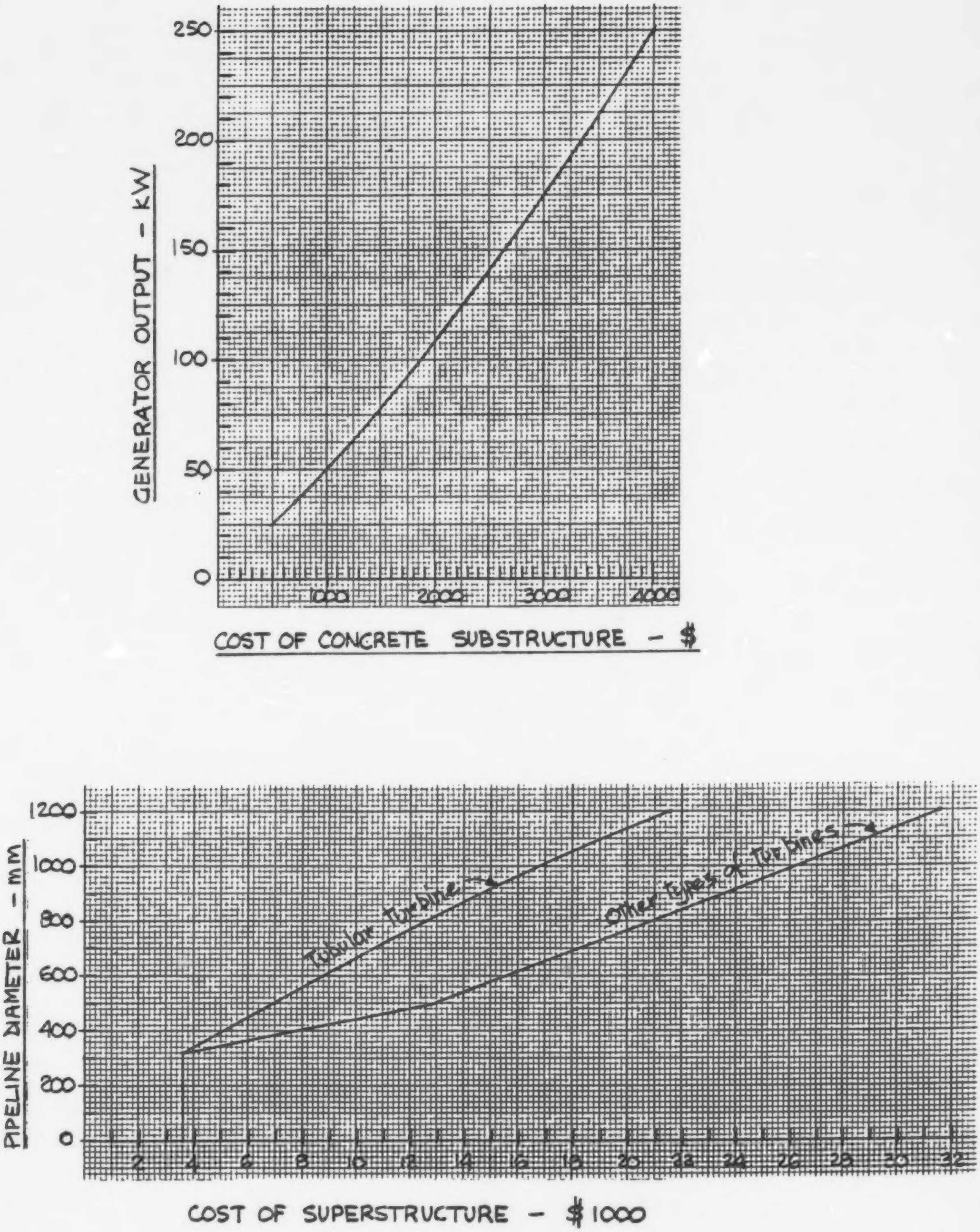
Notes

1. Nominal outside diameter of pipe. The inside diameter will be less and will depend on the gross head.

2. Costs above the heavy line are for polyethylene pipe; costs below the line are for steel pipe.

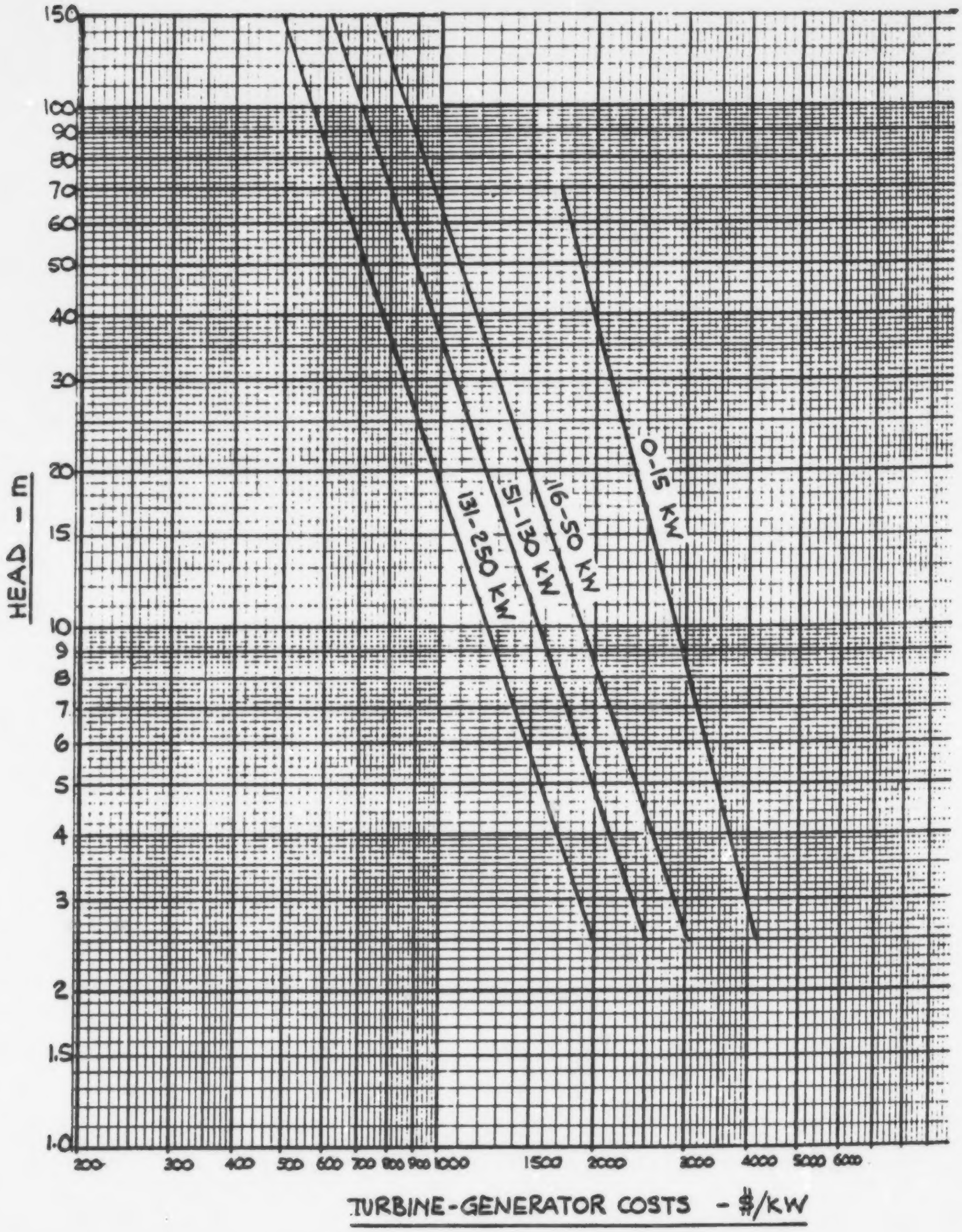
3. Read Section 3.7.1 "Pipeline" in the text to find out how to use this table.

FIG 1.10 PIPELINE COSTS FOR POLYETHYLENE PIPE



Note: Read section 1.8.1 Power House to find out how to use these curves.

FIG 1.11 POWERHOUSE COST



Note: Read section 1.8.1 Turbine Generator and Electrical Equipment, to find out how to use these curves.

FIG 1·12 TURBINE-GENERATOR COSTS

SUPPLEMENT 1.1

MEASURING HEAD AND STREAMFLOW - PRELIMINARY

1.0 MEASURING HEAD

There are several instruments that can be used for measuring head:

- Clinometer
- Hand Level
- Altimeter
- Surveyor's or Engineer's Level.

For a detailed description on how to use these instruments you are advised to check at the library for a book on surveying (two simply-written books are listed in Section F3.0 of this Appendix), or find someone who knows how to use one of the instruments.

1.1 Clinometer

The clinometer is a small hand-held instrument used for measuring vertical angles. With a tape-measure and conversion tables it can be used to measure the difference in elevation between two points, for example, between the turbine and the top of the pipeline, the difference being the head on the turbine.

Figure F1.1 illustrates how a clinometer is used. You need a clinometer, a tape-measure or nylon chain (30 metres or 50 metres long) and a stick with a target (paint mark or piece of tape) at eye level of the person using the clinometer. Standing at Point A, which is where the turbine will be, look through the clinometer and sight on the target held at Point B. Read the vertical angle 01 from the clinometer. Measure the distance AB. Using conversion tables in a survey book calculate the distance CB which is the difference in elevation between A and B.

Move to Point B, your partner moves to Point D. Repeat the measurements of angle 02 and distance BD. Calculate DE. The procedure is repeated until you reach X, the top of the pipeline. Add all the calculated vertical distances BC, DE, etc. together to get the head.

To check the head, or the difference in elevation between Points A and X, the procedure should be repeated in reverse, working from X to A. If the elevation difference from A to X, and X to A is within 2 percent to 5 percent of each other, take the average of the two. If the difference is greater than 5 percent, you should repeat the measurement.

An accuracy of 1 percent to 5 percent can be achieved in measuring differences in elevation with a clinometer when used as described above.

1.2 Hand Level

The hand level is a hand-held instrument used for sighting horizontally (level). Used with a surveyor's rod (a piece of wood with a scale printed on it, held vertically), the hand level can be used to measure differences in elevation.

Figure F1.1 illustrates how a hand level is used. With the hand level at Point B and the rod at Point A (the level of the turbine), a reading is taken on the rod at A_1. A_1 and B_1 are at the same elevation, and both are a distance A_1 above Point A. The rod is now moved to Point C. A reading is taken from B_1 onto the rod at C_1; C_1 is at the same level as A_1. The hand level is then moved to Point D. A reading is taken from D_1 onto the rod at C_2. The difference in elevation between Point A and the hand level at D_1, is equal to the readings $A_1 + (C_2-C_1)$.

Repeat the process, sighting on the rod at E first from D then from F. The difference in elevation between Point A and the hand level at F equals the readings $A_1 + (C_2-C_1) + (E_2-E_1)$. Note the pattern in these readings.

The procedure is repeated until the bottom of the rod is level with the top of the pipeline (at Point X). The difference in elevation between Point A and Point X equals the readings $A_1 + (C_2-C_1) + (E_2-E_1) + \ldots\ldots\ldots + (V_2-V_1) - X_1$.

To check the head repeat the procedure in reverse, from X to A, as described for the clinometer.

The accuracy of measurements with a hand level are about the same as the accuracy with a clinometer.

1.3 Altimeter

An altimeter is a small barometer which measures atmospheric pressure. The dial has two scales, one showing atmospheric pressure, the other showing the elevation in metres (or feet) corresponding to the pressure under normal conditions.

To measure the difference in elevation between the turbine and the top of the pipeline, two altimeters or an altimeter and a barometer should be used. Because the atmospheric pressure is changing continuously, one altimeter or the barometer should be left at one location where someone will read it every hour. This will give a continuous record of the changes in atmopspheric pressure while the other altimeter is used to measure the difference in elevation between the turbine and the top of the pipeline. The elevation difference can then be adjusted by the amount of atmospheric pressure change during the period when readings were taken at the turbine and the top of the pipeline. If these readings are taken within half-an-hour of each other there would be no need to make an adjustment.

An altimeter is useful for measuring differences in elevation (head) greater than about 150 m. To get the greatest accuracy with the instrument measure the difference in elevation (head) at least three times, or until the values of head are within 10 percent of each other. The average of these values should be within 15 m to 20 m of the true value, which would be about 90 percent accuracy for 150 m head. This would be accurate enough for the turbine manufacturer.

2.0 MEASURING STREAMFLOW - PRELIMINARY

2.1 Float Method

The float method is the simplest method for measuring flow, and is suitable for the preliminary calculations of energy discussed in Chapter 1.

The method consists of measuring the velocity of flow by measuring the time a float takes to travel a specific distance; and then measuring the flow area by using a tape-measure or rod to take cross-sections of the stream. The method is described below.

2.1.1 Measuring Velocity

Find a straight section of stream, at least 10 m long (see Figure F2.1). Mark two points on the bank a measured distance apart (call this distance L metres). Use a piece of wood, bottle, cork, or other object for a float. Throw the float into the water upstream of Point A, the upstream point. Measure the time in seconds it takes the float to travel from A to B. Do this several times at different places across the stream, but not too close to the bank where there might be back-eddies.

Take the average of these times (call this T sec). Divide the measured distance L by T to get the average surface velocity. This velocity will be greater than the average velocity of flow in the stream. Multiply the surface velocity by 0.9 to get the average stream velocity.

The average stream velocity is:

$$V \text{ (average)} = \frac{L \times 0.9}{T} \text{ m/sec}$$

Example:

Distance between A and B is 20 m: L = 20 m
Average time to travel A to B is 30 seconds: T = 30 sec.

$$V \text{ (average)} = \frac{20 \times 0.9}{30} = 0.6 \text{ m/sec.}$$

2.1.1 Measuring Stream Cross-Section

It is assumed that the stream is shallow enough so that you can measure the depth either by wading or by standing on a bridge or log across the stream.

Figure F2.1 shows a cross-section of the stream. You want to measure the average cross-section of the flow area for the part of the stream between A and B. Choose a place where the width looks average.

You need a partner and two tapes. Measure the width of the stream at the water surface (shown as W in Figure F2.1). Divide the width into at least 5 equal sections. At the dividing line between each section (i.e., at 1, 2, 3 and 4 in Figure F2.1), measure the depths D_1, D_2, D_3, D_4). Note that if you have divided the width into five equal sections you will have only four depths to measure. Calculate the average depth by adding together the measured depths, and then dividing by the number of sections, which is 5 in Figure F2.1.

The average depth is:

$$\text{D (average)} = \frac{D_1+D_2+D_3+D_4}{5}$$

The cross-section area of flow is:

$$\text{Area} = \text{D (average)} \times \text{W}$$

Example:

Width of Stream = 5 m
Divide width into 5

Depth in m: D_1 D_2 D_3 D_4
0.4 0.5 0.7 0.6

$$\text{Area} = \frac{(D_1+D_2+D_3+D_4)}{5} \times \text{W}$$

$$\text{Area} = \frac{(0.4 + 0.5 + 0.7 + 0.6)}{5} \times 5 = 2.2 \text{ m}^2$$

2.1.3 Calculating Streamflow

The streamflow is equal to the average cross-section area multiplied by the average velocity.

Flow = Q = V (average) x Area

Using the values from the previous examples:

$$Q = 0.6 \times 2.2 = 1.32 \text{ m}^3/\text{sec}$$

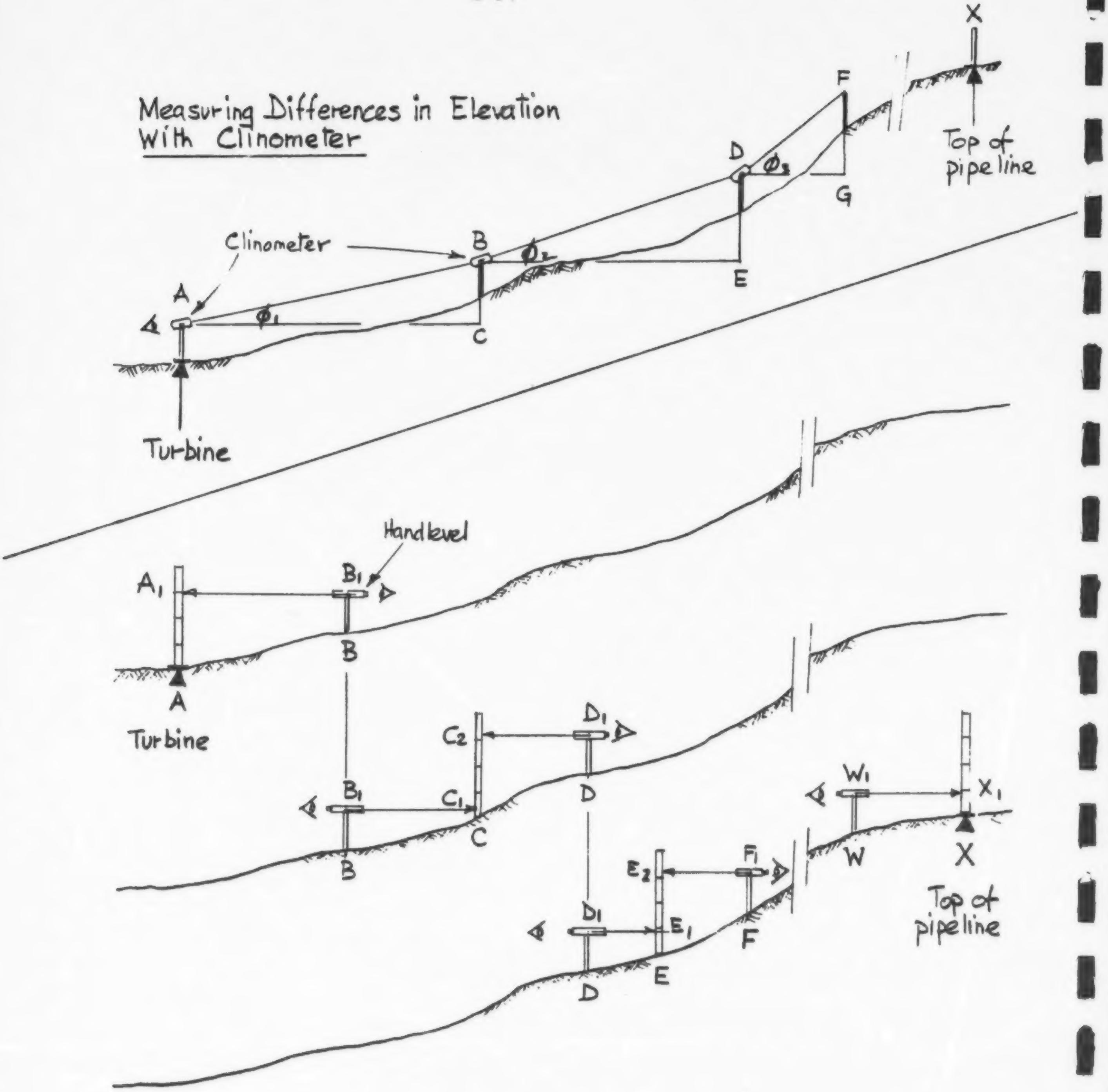
To get a more accurate measurement of flow using this method you could measure the cross-section area at two places, say at A and B (Figure F2.1). Take the average of these areas then multiply by the average velocity.

3.0 REFERENCE BOOKS

3.1 Surveying

R.L. Wilson, "Elementary Forest Surveying and Mapping", Corvallis, Oregon Oregon State University Book Stores, 1981.

"Technical Surveying 1", B.C. Department of Highways and B.C. Institute of Technology, 1973.

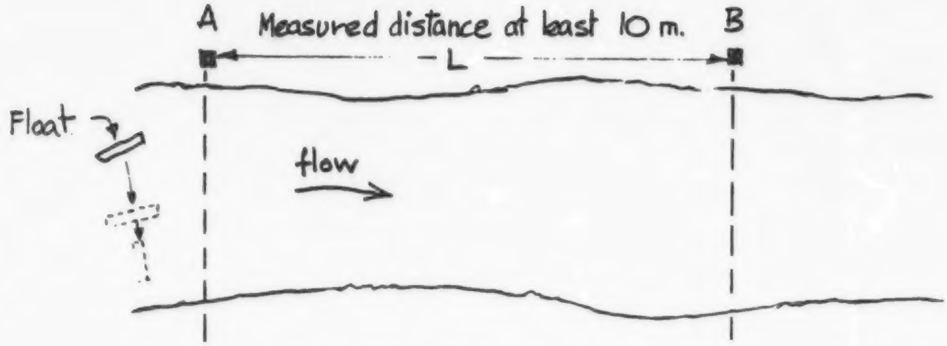

X
F
Top of pipeline
D
ϕ_3
G
Clinometer
B
ϕ_2
E
A
ϕ_1
C
Turbine
Handlevel
A_1
B_1
B
A
Turbine
C_2
D_1
B_1
C_1
D
W_1
X_1
C
B
W
X
E_2
F_1
Top of pipeline
D_1
E_1
F
E
D

Measuring Differences in Elevation With Clinometer

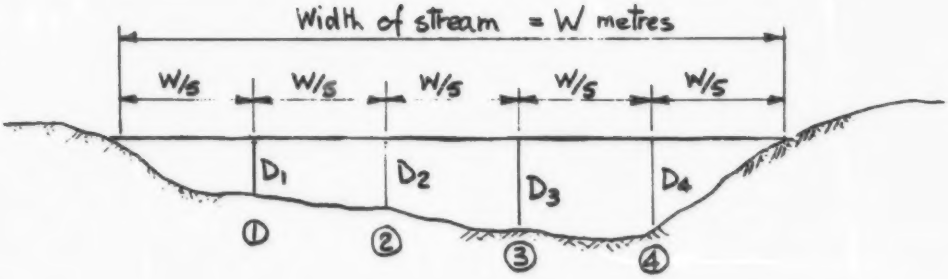
Measuring Differences in Elevation With Hand-Level

FIGURE F1·1

MEASURING STREAMFLOW - FLOAT METHOD


A
Measured distance at least 10 m.
B
L
Float
flow

Plan of Stream


Width of stream = W metres
W/5
W/5
W/5
W/5
W/5
D1
D2
D3
D4
①
②
③
④

Cross-Section of Stream
Between A and B

FIGURE F2·1

2 SITE EXPLORATION AND STREAMFLOW DATA

2.1 INTRODUCTION

Now that you have decided to continue with your project, you need to make a more detailed exploration of the site, and collect data:

(a) to decide on the location to build the dam, intake, pipeline and powerhouse (with more certainty than in Chapter 1), and

(b) to make a more accurate cost estimate (more accurate than using the cost curves in Chapter 1).

Every hydro project is different, and the cost of each structure greatly depends on the site conditions. The cost curves (Chapter 1) are for assumed sites which might be different from yours.

You also need to know more about the flow in the stream to assess more accurately the amount of power and energy you can generate.

The site exploration and streamflow measurements will take time, but the time will be worthwhile if you can avoid some of the problems which might arise should you start to build without this information. For example: you might have problems with access to the intake, pipeline or other structures; you might find the ground is not suitable for building the type of structure you had planned; or you might not have enough flow in the stream nor enough head to get the power and energy you need.

Chapter 2 covers:

(a) topographic maps and streamflow data,
(b) streamflow measurement and water quality,
(c) site selection for the dam, canal, intake, pipeline, powerhouse,
(d) site topography,
(e) need measurement,
(f) transmission line location, and
(g) environmental aspects of building a hydro project.

2.2 TOPOGRAPHIC MAPS

A map of the area can tell you a lot about the hydro project site:

(a) the land title block numbers where you plan to build
(b) the location of any old logging or other access roads,
(c) the upstream origin and the downstream destination of your stream,
(d) the drainage area size, and
(e) the location of any lakes suitable for storage upstream of your site.

From the map you can measure:

(a) the length of the pipeline and transmission line, and
(b) the head for your project, using the contour elevations.

Try to get a map with as large a scale as you can - 1:50,000 or larger (Appendix G tells you what type of maps are available and where to buy them). You can often get the largest scale maps from a logging company or a forester with the provincial Ministry of Forests.

Mark on your map the location of the storage dam and canal (if you need either), the intake, pipeline, powerhouse and transmission line. Put each where you think it should be now, before you go out to look at the sites.

2.3 STREAMFLOW DATA

At this stage, all you need to know is whether or not there is a streamflow gauging station on the stream you plan to use. If there is, and the station is fairly close to your project, you won't have to measure the flow. Ask the Water Management Branch or Environment Canada, Water Resources Branch office in your region if there is a gauge on your stream, or if there has been one in the past.

If you want to know more about your stream (this is not a necessity, but rather an option for the reader who wants to know more about hydrology) ask the Water Management Branch for the name of a nearby stream whose pattern of flows would be similar to the pattern on your stream. Request several years of hydrographs (like the ones in Figure 1.4) showing the flows for the nearby stream. These hydrographs will show how the flows vary during the year. You will need this information in Chapter 3 when you are matching the size of your project to the flow in the stream.

The hydrograph will also help you decide when to measure the flow, that is, the time of the year to expect the lowest or the average flows. (This was discussed in Section 1.4.1 under the subheading "Streamflow Measurements and Estimates.")

2.4 STREAMFLOW MEASUREMENT

You need to know the amount of flow in the stream at different times of the year. Without this information you can't calculate how much power and energy can be produced ... unless the stream is so large that the lowest flow is greater than the flow needed to produce maximum power year-round.

To measure the flow you should INSTALL A STAFF GAUGE, so that you can measure the water level in the stream each day.

The Staff Gauge

A staff gauge is a piece of metal or wood on which a large scale has been painted. It is used to measure the water level, and is mounted in the stream just upstream of a weir or streamflow gauging station. You can buy a gauge or you can make one. Appendix H, in Chapter 3 describes how to make a gauge and how to install it.

Flow Measurement

At this stage, to measure the flow use a Measuring Weir or a Current Meter, rather than the Float Method suggested in Chapter 1. Supplement 2.2 describes how to construct a weir and use it to measure flow. You can use a weir for a small stream, where there is a section not more than about 5 m wide and 1 m deep. You could also use a weir on a larger stream if you are measuring only low flows when there is a section this size or smaller.

For a larger stream you should ask the Water Management Branch to measure the flow several times during the year until you have enough data to plot the stage-discharge curve (detailed below). The Branch would use a flow meter for its measurements.

If the stream flows through a culvert, for example, under a road, this would be a good place to measure the flow. You would have to ask an engineer to calculate the stage-discharge curve for the culvert before you installed the staff gauge.

Stage-Discharge Curve

If you measure the flow and the water level several times when the stream is at different levels, you can plot a curve showing flow against water level. Supplement 2.2 at the end of the chapter tells you how to plot this curve, which is called a stage-discharge curve because it relates stage (water level) to discharge (flow). This curve will tell you what the flow is at any water level. All you do is read the water level from the staff gauge each day, and use the curve to find the flow for that day.

2.5 WATER QUALITY

Water quality here refers to

Suspended sediment, like silt and fine sand
Bed load, including the sand, gravel and rocks that move along the stream bed
Floating debris
Dissolved chemicals
Ice

The operation of a small hydro project could be adversely affected by any of these items. Keep this in mind when selecting the site for the pipeline intake.

Suspended Sediment

Fine sand and silt in the water can cause wear on the turbine runner and blades. Note whether the water in your stream is clear or opaque during normal flows, and during floods caused by heavy rain. The turbine manufacturer will want to know this. (Chapter 3, Section 3.9, tells you what information to give to the turbine manufacturer.)

Some of the larger grains of suspended sediment can settle out of the water before it enters the pipe, in the headpond created by the intake weir, or in a sediment trap.

Bed Load

The sand and gravel that moves along the streambed can quickly block the pipe intake, particularly after a heavy rainstorm. Try to assess the amount of sand and gravel that the stream is carrying. Note where sand and gravel is deposited, and avoid those places when locating your intake.

Dissolved Chemicals

Normally, the concentrations of chemicals in the water are not high enough to cause corrosion in the pipeline, valves or turbine. If you suspect that there are unusually high concentrations of any chemicals in your stream - for instance orange or brown stains on rocks could indicate the presence of dissolved iron oxides, or white deposits near "alkali" lakes - ask the Water Management Branch for information on water quality in the area. The turbine manufacturer should be told of any unusually high concentrations of chemicals.

Ice

Ice effects on small hydro plants are discussed in Chapter 9, so if your stream freezes in the winter be sure to read that Chapter. Note how frazil ice is formed and how it can block water passages. Is your stream turbulent enough in winter to form frazil ice? How deep would the headpond have to be to eliminate the ice problems? The answers are given in Chapter 9.

2.6 SITE SELECTION FOR PROJECT STRUCTURE

This section outlines some considerations when selecting a place to build a dam, intake, pipeline or powerhouse. Details of the structures themselves are given in Chapter 4.

Dam Site

Most small hydro projects will be run-of-river installations without a storage dam. However your project might need a storage dam. The following guidelines refer to intake weirs as well as storage dams.

Good dam sites can be found:

(a) at the top of a steep part of the stream, where the head can be used while keeping the pipeline short;

(b) at a narrow part of the stream channel, where the dam can be kept short;

(c) at a narrowing after the stream flows through a wide, flat area, which would create a good headpond or storage reservoir upstream; or

(d) at the outlet of a lake, which would be a storage dam.

When you have chosen the dam site, make note of

(a) foundation material:
  - Dig a hole through the topsoil to a depth equal to the dam height
  - Take a photograph
  - Take a sample (to show an expert when seeking advice)
  - Note any rock outcrops

(b) site access:
  - locate any existing roads or trails
  - identify possible locations for new access road

(c) alternative dam site:
  - explore upstream and downstream to identify other possible sites

Existing Dam

On a nearby stream you might find an old dam built for a home, a mine, a logging camp, a sawmill, or irrigation. Find out who owns the dam and if you can use it. Check for the following:

1. Is the head sufficient for the power you need?

2. Can a pipeline be installed in or beside the dam?

3. Is the dam in good condition? (If the dam is higher than 2 m you should ask an engineer to check.)

4. How much work would be needed to repair the dam and what would be the costs.

Intake and Pipeline Sites

In selecting a site for the intake to the pipeline (whether the intake is part of a weir or free-standing), and the pipeline itself, check for the following:

(a) pipe submergence:
  - Will there be at least 0.5 m of water above the top of the pipe? (Check Chapter 4 for submergence required.)

(b) sedimentation:
  - Is the selected location away from existing accumulations of sediment in the stream?
  - Can the area upstream of the intake be easily cleared of sediment?
  - Is there space for a sediment trap?

(c) pipeline route
  - Is there access to the whole route;
  - Can you bury the pipe if you choose plastic pipe material?
  - Is the ground firm enough for supports for a steel pipe?
  - Where are the stream crossings and road crossings? (Mark these on your map) Do you expect any problems with the crossings?

Powerhouse Site

When selecting a site for the powerhouse keep in mind the following points:

(a) proximity to the load:
  - Is the powerhouse as close as possible to your house, camp, or mill?
  - How will the power be transmitted to where you need it?

(b) access:
  - Will transport of the turbine-generator unit to the powerhouse be a problem?

(c) powerhouse elevation:
  - Is the powerhouse located low enough to take full advantage of the head available?

(d) tailrace:
  - Is there a good location for the tailrace to discharge water from the turbine without damage to the powerhouse or any other existing structure?

(e) alternative sites:
  - Are there alternative sites that might be better? Would it be cheaper to move the powerhouse closer to the bottom of a steep section of the stream, thereby reducing the penstock length and possibly increasing the length of the transmission line?

Transmission Line Location

Transmission line technical details such as conductor size and span, and clearance between conductors, are discussed in Chapter 4.

When locating the transmission line (if you need one) or the power cable between the powerhouse and the load, consider the following points:

(a) construction access

(b) poles locations:
  - Maximum length of conductor between poles
  - Clearance of conductor from trees, buildings
  - Condition of ground for digging holes for poles, that is rock or soft ground
  - Guys for poles

(c) underground or underwater cables:
  - Feasibility and cost compared to overhead lines
  - Limiting lengths

2.7 HEAD MEASUREMENT

An accurate measurement of gross head (see Figure 1.2 for definition) is needed for calculating the power output of the plant and for calculating the thickness of the pipeline. The turbine manufacturer will also want to know the gross head.

The intake and powerhouse locations, which you selected during your site exploration, might differ from the initial locations selected in Chapter 1. You should measure the gross head again, more carefully than you did in Section 1.4.2.

For more accurate measurements use the instruments indicated below for the different ranges of total head being measured:

Head	Instrument
up to 60 m	Clinometer, Hand Level or Surveyor's Level
60 - 150 m	Hand Level or Surveyor's Level
more than 150 m	Surveyor's Level or Altimeter

You will probably have to rent or borrow these instruments. Appendix F at the end of this chapter discusses their uses.

Mark the points at which you start and finish your measurements, at the pipeline intake and powerhouse - a nail in a tree, or a paint mark on a tree or rock will do. If there are any changes in the location of the intake or powerhouse later on, you will be able to measure from these marks.

2.8 PIPELINE LENGTH

Measure the length of the pipeline again, now that you know more definitely where it will be. Use a tape (30 metres or more long) or a surveyor's nylon chain (50 metres long); or you could make your own nylon chain similar to the surveyor's chain marked off in 10 m divisions, and use a tape for measurements under 10 m.

Mark the route with surveyor's plastic tape, so that you can find it several months later. Draw a sketch of the route as you measure it and write down each measurement. Make notes of where there will be bends, stream crossings, road or trail crossings, and where there might be obstacles such as large trees, rock outcrops or steep hill sides to go around. Mark the beginning and end of the measured length.

2.9 PROJECT SITE TOPOGRAPHY

When exploring the project site be aware that the following might affect or be affected by the project:

- Land and property flooding
- Unexpected changes in stream channel
- Earth or rock slides
- Topographic surveys

Flooding

If you are building a storage dam, make sure you know how much land will be flooded, and who owns the land. Check that there aren't any surrounding areas lower than the top of the storage dam; water might leak through the low spots and cause damage. Even a two metre high intake weir could flood someone else's property, especially when the stream is flowing full.

Changes in Stream Channel

The stream could change its course and by-pass your intake. In some streams the channel changes from year to year. Such streams usually have little slope and carry a lot of sand and gravel. As the flow changes during the year, sand and gravel deposits can cause the stream channel to change course.

If your stream has a lot of sand and gravel which shows up at low water, walk a long way upstream of your intake and try to determine if the stream has changed its course in the last few years. Look for changes in growth of trees and brush along the bank: young trees one to two metres high might indicate the location of where an old stream channel. Could the stream change its course again?

Log jams can cause a stream to flow out of its normal channel and make a new channel. Check your stream for log jams upstream of where you plan to build the intake.

When selecting the site for the intake weir, check that at high flow the weir does not divert water out of the normal channel upstream of the weir.

Earth and Rock Slides

Avoid digging into steep banks or slopes when building any structure: intake, dam, pipeline or powerhouse. You might cause an earth or rock slide.

Even fairly flat-looking slopes can slide. Check for evidence of previous slides on slopes near the sites of the structures you plan to build.

Topographic Surveys

Topographic surveys, which can be used to draw detailed contour maps of certain areas, will be needed to

(a) design a storage dam
(b) design an intake weir or dam over 1.5 m high
(c) assist contractors bidding on the construction of any structure, and/or
(d) provide information to the Water Management Branch, if there is a possibility of flooding property.

Unless you have prior experience, topographic surveying should be done by a surveyor or an engineer.

2.10 ENVIRONMENTAL ASPECTS

Even a small hydro project can have a significant effect on the environment. Consider the impact of your project on

- Fish
- Trees
- Visual effect

Fish

Ask the regional office of the Provincial Fish and Wildlife Branch if there are any restrictions on building a hydro project on your stream. You should know this as soon as possible; there can be definite restrictions on salmon spawning streams.

A small hydro project could have the following impact on fish:

(a) prevent fish from migrating up or down the stream;
(b) kill young fish in the turbine;
(c) change the sediment in the stream and alter the gravel bars where fish spawn.

Trees

Trees and other plants will be affected in several areas:

(a) along the banks of the stream;
(b) in the storage reservoir area;

(c) at the construction sites, such as, access roads, dams, pipeline, powerhouse, tailrace, transmission line.

Building your project could change the course of the stream in certain areas; the banks could be undermined, causing trees to fall into the stream; and this could cause log jams, flooding, and clogging of the intake trash racks. These problems could occur during the first high flows in the stream after the project is built.

If you are going to build a storage dam, you should clear the brush and trees from the area that will be flooded. Otherwise you will have dead, rotting trees in the reservoir for many years.

At the construction sites, don't cut more trees than are necessary.

At the tailrace, make certain that water from the turbine is directed back into the stream, or into a lake or the sea, with minimum disturbance to trees and vegetation.

Consider using all the timber you cut. Saw it into lumber for formwork or the powerhouse superstructure, or use it as logs in a rock-filled timber-crib dam or retaining wall.

Visual Effects

Try to minimize the visual impact of your hydro project on the stream and surrounding land, particularly if you are using Crown land or other people's property on which to build the structures.

An earthfill dam will soon blend into the surroundings if the area disrupted during construction is cleaned up and seeded.

A low concrete weir across a stream will be less obtrusive without protrusions such as reinforcing bars, steel guides for stoplogs or gates, a stem for operating a valve or gate, or old formwork.

Keep the pipeline out of the stream bed (it's vulnerable to damage there anyway), and bury it if you can.

Build the powerhouse to be as visually pleasing as your own house.

SUPPLEMENT 2.1

MAPS, AIR PHOTOS, STREAM FLOW AND CLIMATE DATA

1.0 MAPS

1.1 Maps Published by Federal and Provincial Governments

The National Topographic Series of maps can be used to help you plan your hydro project. Different editions of these maps, with different scales and features, are published by the Federal and Provincial governments.

Maps Published by Federal and Provincial Governments

		Contour Interval		
Published by	Scale	m*	ft	Coverage of B.C.
Federal Govt	1:25,000 (0.4in=1mile)	-	10	Vancouver, Fraser Valley
	1:50,000 (1.3in=1mile)	20 or 40	100	Most of B.C.
(older series)	1:250,000 (1in=3.9miles)	-	500	All of B.C.
Provincial Govt	1:126,720 (1in=2.0miles)	-	100	All of B.C.
	1:100,000 metric			
	1:125,000 (1in=2.0miles)	50	(150)	All of B.C.
(older series)	1:250,000 (1in=3.9miles)	(150)	500	All of B.C.

* Metric contours are used on maps after 1980.

There is a project of remapping the province at 1:20,000, base maps. In some cases, the Province may have contours available.

1.2 What Features are Shown on Maps

The following features shown on these maps will be useful when planning your hydro project:

Streams, rivers, lakes, marshes, glaciers;
Highways, roads, logging roads, trails;
Contours;
Areas covered with trees are shown green on Federal maps;
District lot lines are shown on all maps;
Alienated land or land covered by application under the Land Act is distinguished on Provincial Government editions only.

1.3 Index Maps

Index maps of B.C. show the parts of the province that are covered by maps of different scales. Write to one of the government addresses given below and ask for Index Maps and a price list.

1.4 Where to Buy Maps

Maps can be obtained from the following government agencies:

Federal maps of B.C. and the Yukon:

Geological Survey of Canada
100 West Pender Street
Vancouver, B.C. V6B 1R8 Phone: 666-0271

Map cost (Sept. 1987) $4.00 per map, plus tax

Maps of B.C. published by the Provincial Government:

Maps of B.C.
Ministry of Environment
Parliament Buildings
Victoria, B.C. V8V 1X5 Phone: 387-1441

Map cost (Sept. 1987) $4.00 per map.

Provincial government agents usually have maps available for viewing or purchasing. Check with your telephone directory for the government agent nearest you: there are over 60 agents in B.C.

If you are in Vancouver, you can buy maps from:

Dominion Map Ltd.
1104 West Broadway
Vancouver, B.C. Phone: 684-4341

Map cost (Sept. 1987) $5.00 per map.
(take Visa; or cheque with order)

or

World Wide Books and Maps
949 Granville Street
Vancouver, B.C.

2.0 AIR PHOTOS

2.1 What Air Photos Can Show

Air photos can show you many features that cannot be seen on a map, and often features that cannot be sensed from the ground, such as:

(a) the nature of the stream and its banks near the proposed point of diversion -- there might be a better site just upstream or downstream;

(b) old stream channels, which could be used for diverting flow into the pipeline, or which should be watched for possible flooding at high flows:

(c) lakes or marshes which could be used for storage;

(d) rock outcrops which could make the construction of an access road or a pipeline difficult;

(e) areas of old or active rock slides or snow avalanches.

The photos are taken in stereo pairs and can be viewed through a stereoscope to give an exaggerated impression of topography, heights of trees and other features.

2.2 Where to Buy Air Photos

The Federal and Provincial governments have taken air photos of parts of B.C. Photos taken by the provincial government can be bought from:

Maps B.C.
553 Superior Street
Victoria, B.C. V8V 1X5 Phone: 387-1441

Photos taken by the Federal Government can be bought from:

National Air Photo Library
615 Booth Street
Ottawa, Ontario K1A 0E9 Phone: (613) 995-4560

There is a library of air photos taken by the Federal and Provincial governments at Maps B.C. (address given above) Air photo prints, like maps, are produced at different scales, approximately as follows:

1 inch to 1 mile, or 5280 ft per inch
1 inch to 1/2 mile, or 2640 ft per inch
1 inch to 1/4 mile, or 1320 ft per inch
Special Project photos at 400 ft or 500 ft per inch

The photos were taken at different times, some as long ago as 1933. Generally, the most recent photos would be the best; however, in some areas, slightly older photos, taken after an area had been logged off, might show more information about the stream and the topography. When ordering air photos, give the government agency the exact area you want covered, or the name of the creek, preferably with map references. There are index maps available, but unless you have had experience reading them they are hard to use.

If you are in Vancouver you could visit Norman Wade Co., who have index maps and will help you find the photos you want; they will also order the photos from Victoria.

Norman Wade Co.
1603 West 3rd Avenue
Vancouver, B.C.   Phone: 736-6323

3.0 STREAMFLOW DATA

3.1 What Data is Available

Records of daily streamflows are available for many rivers and creeks in B.C. From these daily flows, Water Survey of Canada (W.S.C.) have made summaries of the following data, for each stream:

(a) monthly and annual mean flows:
(b) maximum and minimum daily flows in each year of record;
(c) frequency graphs of annual maximum daily flows and annual 7-day low flows.

The monthly mean flows show how the flow in a stream varies during the year; the annual mean flows show how the flows vary from year to year. When planning your hydro project it is useful to know what the lowest monthly and annual flows have been, and to realize that future flows could be much lower than the recorded flows.

The frequency graphs show how often to expect flows of a certain magnitude (high flows or low flows) in the future; or the magnitude of flow to expect, for example, once in 10, 20, 50 to 100 years.

3.2 Where to Get Streamflow Data

Streamflow data can be obtained from:

Water Resources Branch, Inland Waters Directorate
Environment Canada
Room 502
1001 West Pender Street
Vancouver, B.C. V6E 2M9   Phone: 666-3610

You might also be able to get streamflow data from the regional office of the provincial Water Management Branch nearest you. Ask this office if any flow measurements or studies have been made on the stream you propose to use for your hydro project. The addresses are:

Kamloops:

Regional Manager
Water Management Branch
1259 Dalhousie Drive
Kamloops, B.C.
V2C 5Z5 Phone: 374-9717

Nanaimo:

Regional Manager
Water Management Branch
2569 Kenworth Road
Nanaimo, B.C.
V9T 4P7 Phone: 758-3951

Nelson:

Regional Manager
Water Management Branch
310 Ward Street
Nelson, B.C.
V1L 5S4 Phone: 354-6372

Smithers:

Regional Manager
Water Management Branch
Bag 5000
Smithers, B.C.
V0J 2N0 Phone: 847-7275

Surrey:

Regional Manager
Water Management Branch
10334-152A Street
Surrey, B.C.
V3R 7P8 Phone: 584-8822

Penticton:

Water Management Branch
3547 Skaha Lake Road
Penticton, B.C.
V2A 7K2 Phone: 493-8261

Prince George:

Regional Manager
Water Management Branch
1011-4th Avenue
Prince George, B.C.
V2L 3H9 Phone: 565-6432

Victoria:

Hydrology Section
Water Management Branch
Parliament Buildings
Victoria, B.C.
V8V 1X5 Phone: 387-1111

4.0 CLIMATE DATA

4.1 What Data is Available

There are many more climate stations than streamflow stations in B.C. Most communities have a climate station where volunteers keep records of daily precipitation and daily maximum and minimum air temperatures.

For planning your project, it will be useful to have precipitation and air temperature data for a station near the project. You will probably be most interested in droughts and extremely low temperatures.

The length of a drought, which is a period of time without precipitation, will enable you to estimate how long extremely low flows can be expected to last. This will help you to decide if you need a storage reservoir or an alternative source of power.

You will also want to know how low the air temperatures have been, so that you can decide if the hydro project needs to be protected from ice at the intake or in the pipeline. (See Chapter 9 for cold weather considerations).

The types of data that are available are:

(a) daily precipitation;
(b) daily maximum, minimum and mean air temperatures;
(c) monthly and annual values of:
  - mean precipitation;
  - maximum 24 hour precipitation;
  - maximum, minimum and mean daily temperatures;
  - number of days with precipitation;
  - number of days with frost.

4.2 Where to Get Climate Data

Climate data is collected and published by the Federal Government, through the Atmospheric Environment Service (AES); and by the Provincial Government, through the Ministry of Environment.

Data can be obtained from:

Atmospheric Environment Service
Suite 700
1200 West 73rd Street
Vancouver, B.C.
V6P 6H9 Phone: 666-2980

or

Environment Services Section
Waste Management Branch
Ministry of Environment
Parliament Buildings
Victoria, B.C.
V8V 1X5 Phone: 387-4321

Phone or write for data for several stations near your project. Ask for specific data, for example, monthly summaries of air temperatures for the period of record, or daily temperatures for the coldest winter of record. There is a small charge for the data from AES, and you don't want more data than you can use. The Water Management Branch office nearest you (addresses given in Section 3.2 above) might have the climate data you want.

SUPPLEMENT 2.2

INSTALLING A STAFF GAUGE AND WEIR TO MEASURE STREAMFLOW

1.0 INSTALLING A STAFF GAUGE TO MEASURE WATER LEVEL IN A STREAM

A staff gauge is a piece of wood or metal painted with a scale, and set permanently in a stream to enable the water level to be read each day. The daily water levels can be converted to streamflow using a stage-discharge curve, as explained in Section 3.0.

1.1 Making a Staff Gauge

Your staff gauge must be sturdy enough to last several months and to withstand high flows and floating debris. The painted scale must be accurate and durable. Use good grade plywood, sawn lumber, metal or plastic. Wooden scales should be painted with an undercoat on all surfaces.

Figure H1 shows how the graduations should be painted. The length of the gauge should be greater than the difference between the lowest and highest waterlevels in the stream. Look for high watermarks on the bank; the lowest level will be the top of the weir you will be building.

1.2 Installing a Staff Gauge

The painted scale should be fixed to a length of lumber or a sturdy post. Install the post before attaching the scale, because the bottom of the scale must be accurately positioned.

Locate the post in smooth water upstream from the weir a distance of at least 1.0m, or at least three times the maximum height of water over the top of the weir; this is shown in Figure H1. Make sure you can read the scale from the bank at high and low water. Brace the post to a tree or rock so that it will not be moved by high flows or debris.

When you have built the weir (as explained below), carefully level from the top of the weir back to the post, and fix the scale with the zero mark at the level of the weir as shown in Figure H1. For a v-notch weir, the zero mark should be level with the bottom of the "V".

2.0 INSTALLING A WEIR TO MEASURE FLOW

A weir is used to simplify the hydraulics of the stream so that the flow can be calculated from the water level only, without measuring the stream cross-section. Weirs of standard shapes have been tested in laboratories and formulae have been developed for calculating the flow passing over them.

A wooden weir, as described here, is suitable for measuring flows up to about 18 m^3/s. For measuring flows greater than this, a current meter should be used. You could ask the Water Management Branch, Water Survey of Canada, or an engineer to do this.

2.1 Building a Weir

Three types of weir are shown in Figure H1. They can be made from a single piece of plywood and are suitable for flows up to about 2 m^3/s. For flows greater than this, up to about 18 m^3/s, you could build a rectangular weir out of sawn lumber. The weir should be the same shape as in drawing (b), but wider.

If you use plywood, use a grade that has solid edges, then paint or warnish it to protect the edges from delaminating. The edges over which water flows should be bevelled at about 45° (see Figure H1 drawing (d)). To protect these edges from damage by debris, cover them with sheet metal such as flashing.

When installing the weir pay special attention to:

(a) strong supports to prevent movement under high flows;
(b) sealing along bottom and sides to prevent leakage and erosion: use plastic sheeting as shown in Figure H1.

3.0 MEASURING FLOW AND PLOTTING A STAGE-DISCHARGE CURVE

3.1 Using Weir Discharge Tables to Find Flow

Table H2 shows flows for different depths of water over three types of weir. Select the part of the table which applies to your type and size of weir -- you might want to draw a line around the columns of flow that apply to your weir to make sure you always use the correct values.

To keep a daily record of water levels and flows, set up a table like the one in Table H1(A). Enter the date, the time of measurement and the staff-gauge reading (water level). Always read the staff-gauge at about the same time each day because that one reading will be assumed to be the average for the day. Use Table H2 to find the flow for each gauge reading and enter the flow in column 4 of your record sheet.

Example:

A rectangular weir, 2.0m wide
Gauge reading 50 cm
Use Table H2 column 3 which applies to a 2.0m wide rectangular weir
Opposite a gauge height of 50 cm read the flow as 1.23 m^3/s

3.2 Plotting a Stage-Discharge Curve

A stage-discharge curve, such as the one in Figure H2, is a plot of water level versus the flow in the stream. The curve provides the same information as a weir discharge table like Table H2; however, usually, a curve shows flows higher than could be measured with a temporary weir.

You might need a stage discharge curve for the following reasons:

(a) if you have a temporary measuring weir and you want to record flows after the weir is removed;
(b) if you want to record flows that are greater than you can measure with a weir;
(c) if you don't have a measuring weir, or if the stream is too large for a measuring weir.

If you want to record flows after the temporary measuring weir is removed, you will have to install two staff-gauges; one for the weir, and the other as a permanent gauge that will not be affected when the weir is removed. While the weir is in place you would read both gauges each day at the same time and enter the readings in a table similar to Table H1(B), in columns 3 and 5. The discharges in column 4 would be read from the weir tables using the weir gauge readings in column 3. You would then plot the discharge values in column 4 against gauge readings in column 5 from the permanent gauge. These points would help you draw the lower part of the stage discharge curve, as shown by the line AB in Figure H2, and as explained in the example below.

You will probably want to record flows that are higher than the flows you can measure from your weir. An engineer could help you with these higher flows by measuring the flows with a flow meter or calculating the flows using stream hydraulics.

With the readings from the weir and a few higher flows that have been measured or calculated, a stage-discharge curve can be drawn to cover most of the flows that would be expected in the stream. This is explained in the following example:

> Flows were required for a steep, rocky stream that flowed through a 4m diameter road culvert. During the summer dry period the flows were too low to calculate from the hydraulics of the culvert, so a 90°V-notch weir was installed about 30m upstream from the culvert. A staff gauge wass installed just upstream of the weir, and a second staff gauge was installed 3m upstream of the culvert.
>
> Water levels were read at both gauges for 15 days (the readings are shown in Table H1(B), columns 3 and 5, July 3 to August 17). When the first rainstorm came in October the weir was washed out. Thereafter, water levels were read daily at the culvert. On four days during the high flow period, measurements of water levels were taken in the culvert, from

which flows on those days were calculated (these values are shown in column 6).

The flow values in Table H1(B), column 4 were read from Table H2 column 2. The stage discharge curve in Figure H2 was plotted from the values in Table H1(B). The lower points on the curve were plotted from columns 4 and 5 in Table H1(B). The four upper points were plotted from values in columns 5 and 6. A smooth curve was drawn through all the plotted points.

So long as the stream bed does not change, a stage-discharge curve will give the flow at any gauge reading.

TABLE A

(A) TYPICAL WATER LEVEL & DISCHARGE RECORD FORM

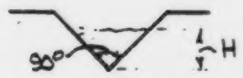
COL. 1	2	3	4	
DATE	TIME	WATER LEVEL: STAFF GAUGE READING cm	DISCHARGE m³/s	NOTES: eg. initials of gauge reader; weather - temp & rain.
				(2.0 m wide rectangular weir)
1985				
June 5	8:10	45.5	1.07	PF
6	8:15	46	1.09	PF
7	8:10	50	1.23	PF heavy rain last night
8	8 25	49	1.20	AF
10	8:05	48	1.16	PF

(B) WATER LEVEL & DISCHARGE DATA FOR PLOTTING STAGE-DISCHARGE CURVE

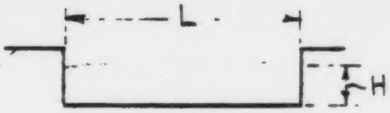
COL. 1	2	3	4	5	6	
DATE	TIME	STAFF GAUGE READING AT WEIR cm	DISCHARGE FROM WEIR TABLE m³/s	STAFF GAUGE READING OF PERMANENT GAUGE cm	DISCHARGE MEASURED OR CALCULATED m³/s	
1984						
July 3	9:05	50.5	.25	19.0		FP
5	8:50	50.5	.25	19.0		FP
7	8:30	50.0	.24	18.5		FP
8	8:30	49.5	.23	18.2		FP
10	8:15	47.0	.21	17.5		FP
11	8:30	46.5	.20	16.5		FP
13	8:40	45.5	.18	15.0		FP
14	8:30	46.0	.19	15.5		DR
16	8:00	44.0	.18	15.5		DR
23	8:30	39.5	.13	13.8		FP
27	8:10	36.5	.11	12.5		FP
31	8:15	33.0	.086	11.0		DR
Aug 6	8:00	34.0	.092	10.5		FP
13	8:10	34.5	.095	10.5		FP
17	8:00	34.0	.092	10.4		FP
Oct 3	8:50			57.0	2.00	JB
7	8:40			50.5	1.57	JB
8	10:00			48.0	1.65	JB.
20	9:05			58.5	2.10	JB

TABLE B

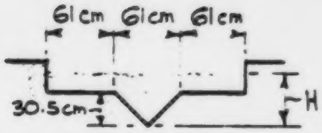
DISCHARGE OVER WEIRS



90° V-NOTCH WEIR



RECTANGULAR WEIR



COMPOUND WEIR

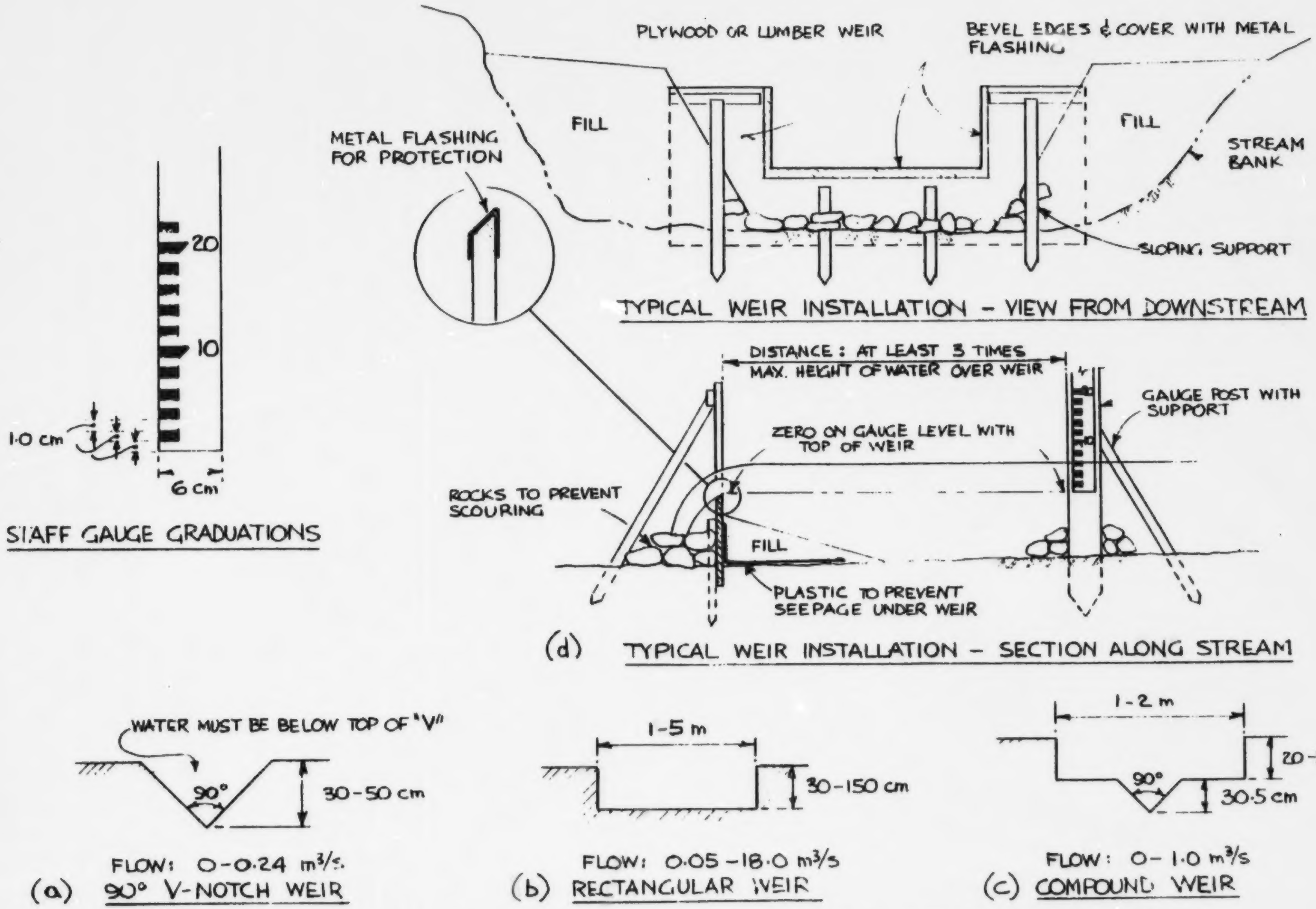
CM = CENTIMETERS
M^3/S = CUBIC METRES PER SECOND

	90° V-NOTCH WEIR	RECTANGULAR WEIR L = 2 M	RECTANGULAR WEIR L = 4 M	COMPOUND WEIR
H CM	DISCHARGE M^3/S	DISCHARGE M^3/S	DISCHARGE M^3/S	DISCHARGE M^3/S
10	.004	.12	.23	.004
12	.007	.15	.30	.007
14	.010	.19	.38	.010
16	.014	.23	.47	.014
18	.019	.27	.56	.019
20	.025	.32	.65	.025
21	.028	.35	.70	.028
22	.031	.37	.75	.031
23	.035	.40	.80	.035
24	.039	.42	.85	.039
25	.043	.45	.91	.043
26	.048	.47	.96	.048
27	.052	.50	1.02	.052
28	.057	.53	1.07	.057
29	.062	.56	1.13	.062
30	.068	.59	1.19	.068
31	.073	.62	1.25	.074
32	.080	.64	1.31	.084
33	.086	.67	1.37	.095
34	.092	.70	1.43	.11
35	.099	.73	1.50	.12
36	.11	.76	1.56	.13
37	.11	.80	1.62	.15
38	.12	.83	1.69	.16
39	.13	.86	1.76	.18
40	.14	.89	1.82	.20
41	.15	.93	1.89	.22
42	.16	.96	1.96	.24
43	.17	.99	2.03	.26
44	.18	1.02	2.10	.28
45	.18	1.06	2.17	.30
46	.19	1.09	2.24	.32
47	.21	1.13	2.31	.34
48	.22	1.16	2.39	.36
49	.23	1.20	2.46	.39
50	.24	1.23	2.53	.41

TABLE B (CONTINUED)

DISCHARGE OVER WEIRS

	RECTANGULAR WEIR		COMPOUND WEIR
	L = 2 M	L = 4 M	
H	DISCHARGE	DISCHARGE	DISCHARGE
CM	M^3/S	M^3/S	M^3/S
51	1.27	2.61	.43
52	1.31	2.69	.46
53	1.34	2.76	.48
54	1.38	2.83	.51
55	1.42	2.92	.53
56	1.45	2.99	.56
57	1.49	3.07	.59
58	1.53	3.15	.61
59	1.57	3.23	.64
60	1.61	3.31	.67
61	1.64	3.40	
62	1.68	3.48	
63	1.72	3.56	
64	1.76	3.64	
65	1.80	3.73	
66		3.81	
67		3.90	
68		3.98	
69		4.07	
70		4.16	
71		4.24	
72		4.33	
73		4.42	
74		4.51	
75		4.60	
76		4.69	
77		4.78	
78		4.87	
79		4.96	
80		5.05	


PLYWOOD OR LUMBER WEIR
BEVEL EDGES & COVER WITH METAL FLASHING
FILL
FILL
STREAM BANK
SLOPING SUPPORT
METAL FLASHING FOR PROTECTION
20
10
1.0 cm
6 cm
DISTANCE : AT LEAST 3 TIMES MAX. HEIGHT OF WATER OVER WEIR
GAUGE POST WITH SUPPORT
ZERO ON GAUGE LEVEL WITH TOP OF WEIR
ROCKS TO PREVENT SCOURING
FILL
PLASTIC TO PREVENT SEEPAGE UNDER WEIR
WATER MUST BE BELOW TOP OF "V"
90°
30-50 cm
1-5 m
30-150 cm
1-2 m
20-90cm
90°
30.5 cm

TYPICAL WEIR INSTALLATION - VIEW FROM DOWNSTREAM

STAFF GAUGE GRADUATIONS

(d) TYPICAL WEIR INSTALLATION - SECTION ALONG STREAM

FLOW: 0-0.24 m³/s.
(a) 90° V-NOTCH WEIR

FLOW: 0.05-18.0 m³/s
(b) RECTANGULAR WEIR

FLOW: 0-1.0 m³/s
(c) COMPOUND WEIR

FIG A STAFF GAUGE & FLOW MEASURING WEIRS

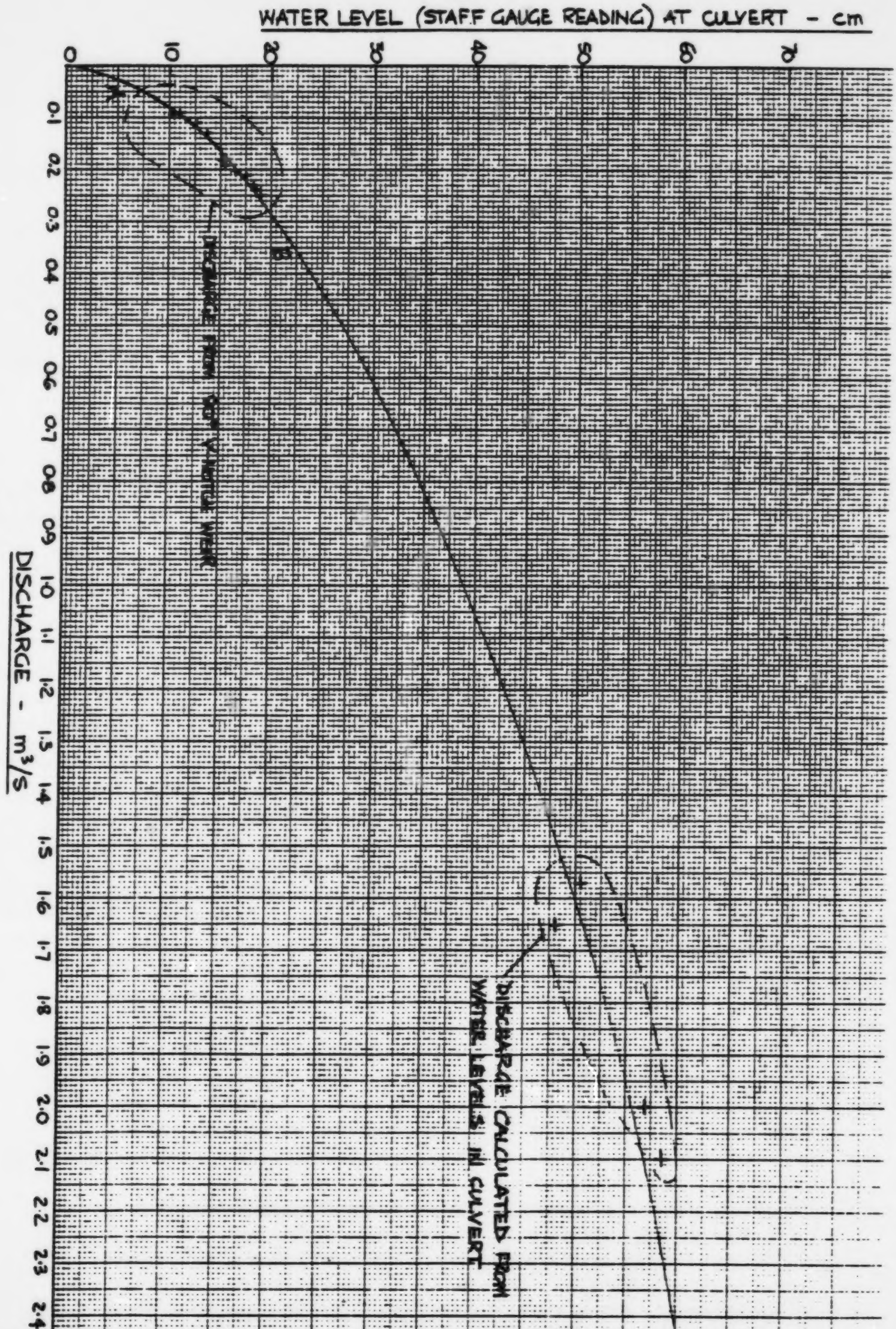


FIG B STAGE-DISCHARGE CURVE

3 ASSESSMENT OF THE FEASIBILITY OF YOUR HYDRO PROJECT

3.1 INTRODUCTION

Before you start the detailed design of your project, you should

(a) confirm that the project is worth building (assess the feasibility of the project),

(b) find the least expensive arrangement for the project (optimize the project), and

(c) prepare information for use in:

Your application for a water licence
Your request for a loan from a bank
Your request for bids on the turbine, generator and other equipment

Some of this work was done in a preliminary form in Chapter 1. Now you will be asked to do a more detailed assessment of your expected loads and the power available from the stream. You will use information you gathered in Chapter 2.

Chapter 3 covers:

(a) making in inventory of your electric loads,
(b) planning and managing your loads,
(c) estimating the power and energy available from the stream,
(d) sizing the hydro plant,
(e) revising the layout of the project,
(f) revising the cost estimate, and
(g) assessing the feasibility of the project.

3.2 POWER AND ENERGY REQUIREMENTS

Power (kW) and energy (kW.h) requirements for a single family residence, a group of residences, and motels and camps are discussed in this section. The maximum power requirement, or maximum load in kW, must be known, prior to deciding the size of hydro plant to build. Your energy requirements, or your electrical consumption in kW.h, will be used to verify the economics of the hydro project.

3.2.1 Energy Conservation

Conserving energy will probably save you money. How much money you save will depend on how far you want to go with energy conserving ideas?

Some suggestions for saving energy were given in Chapter 1, Section 1.2.3. Now is the time to look at one of the publications on energy conservation referenced in Supplement 2.2 Decide which ways you want to save energy, and estimate how monch energy you could save. You will need to know this before you estimate your future power and energy requirements.

3.2.2 Single Family Residence Load Inventory

The best way to estimate your power requirements is to make a list or inventory of the electrical loads in your house. List the loads you have now, and add loads that you expect to have in, say ten years time. With this list you can plan how the loads could be managed (using electronic load management) to reduce the size of the hydro plant.

The example that follows will help you prepare your load inventory.

First you have to assign a category to each load if you want to take advantage of automatic load management, which is discussed in Section 3.3.

The four categories of loads are:

Demand Load:

A load for which power must always be available - e.g. lights, most outlets, security systems, kitchen appliances, or industrial machinery. These loads should not be interrupted by the automatic load management controls.

Short-Term Interruptable Load:

A load that can be turned off for up to 4 hours when power is not available for all loads - e.g. deep-freeze, fridge, dishwasher, sauna.

Long-Term Interruptable Load:

A load that can be turned off for up to 12 hours when power is not available for all loads - e.g. hot water heating, water supply pumping into a storage tank. Usually these loads could be run at night when most of the other loads are off.

Fully Interruptable Load:

A load that can be turned off indefinitely. Normally, these loads would have an alternative source of energy as back-up - e.g. electric space heating with oil or propane back-up. These loads are not normally included in calculating the size of the hydro plant.

Example:

Table 3.1 shows a load inventory for a 3 bedroom house.

Here is an explanation of each column in Table 3.1:

- Column 1 - Loads you expect to have for the next 5 - 10 years.
- Column 2 - The power (kW) each load requires when in use.
- Column 3 - Typical maximum daily usage (hours) for summer and winter.
- Column 4 - Load category - as explained above.
- Column 5 - Loads expected during peak load period in summer (4 pm to 6 pm normally, i.e. the sum of all the demand loads that could be on at the same time); list only Demand Loads in Column 5.
- Column 6 - 24 hour average loads for the day with maximum, summer load equal to Column 2 x Column 3 divided by 24.
- Column 7 - Same as Column 5 for winter.
- Column 8 - Same as Column 6 for winter.

TABLE 3.1

EXAMPLE: LOAD INVENTORY FOR 3 BEDROOM HOUSE

(See Section 3.2.2 for explanation)

1	2	3	4	5	6	7	8
				Load Contribution			
				Summer		Winter	
Description	Rating kW	Daily Use Summer/ Winter Hours	Category	Peak kW	24 Hour Avg kW	Peak kW	24 Hour Avg kW
General:							
Lights	1.2	3/8	D	1.2	0.15	1.2	0.40
Space Heat.	10.0	2/15	S		0.83		6.25
Hot Water	4.0	8/8	L		1.33		1.33
Washer	0.6	1/1	S		0.03		0.03
Drier	2.5	1/1	S		0.10		0.10
Radio/Ster.	0.1	3/5	D	0.1	0.01	0.1	0.02
T.V.	0.3	3/5	D	0.3	0.04	0.3	0.06
Water Pump	1.0	3/3	L		0.13		0.13
V. Cleaner	0.8	0.5/0.5	S		0.02		0.02
Kitchen:							
Fridge	0.5	12/8	S		0.25		0.17
Deep Freeze	0.4	12/12	S		0.20		0.20
Micro. Oven	1.2	1/1	D	1.2	0.05	1.2	0.05
Toaster	1.2	0.1/0.1	D	1.2	-	1.2	-
Blender	0.6	0.1/0.1	D	0.6	-	0.6	-
Workshop:							
Table Saw	1.0	2/2	D	1.0	0.08	1.0	0.08
Skill Saw	1.0	2/2	S		0.08		0.08
TOTALS (kW)	26.4			5.6	3.28	5.6	8.85
TOTALS WITHOUT SPACE HEATING				5.6	2.45	5.6	2.60

D = Demand Load; S = Short-Term Interruptable Load; L - Long-Term Interruptable Load

Look at the total loads at the bottom of the table. If all the loads were on at the same time - which is unlikely but possible - the total load would be the sum of all the rated loads: 26.4 kW. You would need a power plant of about 30 kW.

With automatic load management (discussed in Section 3.3) the maximum average daily load would be 8.85 kW. (This is the maximum total of Columns 5 to 8.) A 10 kW power plant would be large enough to meet this load; and in summer only about 6 kW of power would be required to meet the demand loads. (Matching the plant size to the loads is discussed further in Section 3.5.)

This example illustrates the need for a reasonably accurate assessment of your loads, to make sure you install the proper size of power plant.

Your Load Inventory

List each load you expect to have for the next five years to ten years, and estimate the maximum amount of time each would be used during the day. Use the form on Table 3.2 for this. Examples of how loads can vary during the day and at different times of the year are discussed below under the heading "Load Variations". Typical load ratings and typical daily usage times of appliances used in the home are given in Table 3.3.

If you think the daily usage values in Table 3.3 do not represent your situation, you can keep a log of your own loads for several days; preferably for at least a week to show you how your use of electricity varies from day to day. Table 3.4 is a Daily Load Log you could use, and Table 3.5 shows an example of a completed log. List all your loads in the left hand column and write the rated demand (kW) in the next column. Then, each half-hour (or hour), enter a line in the chart for each load that was on. You probably won't be able to do this throughout the day, but it should be done during the normal peak load times around 1 pm and between 4 pm and 6 pm. At the end of the day add up the loads for each time period (half-hour or hour) and enter the maximum value for each hour at the bottom of the table.

You can use these daily logs to estimate your normal usage times for each area, and also to estimate your hourly loads. This information can then be used on your load inventory in Table 3.2.

Now complete your inventory in Table 3.2, referring to the example in Table 3.1 when necessary. To check the rated load of electrical space heating use the Maximum Load (kW) values for the applicable insulation level, as given in Table 3.6. Remember all heaters don't have to be on at once and some are more important than others.

Load Variations

Examples of how power loads (kW) normally vary during the day and throughout the year will help you to estimate your expected loads.

The graphs on Figure 3.1 show typical variations of residential loads. The two lower curves show typical daily loads in winter and summer for residences with average electrical consumption (kW.h). The curves are averages taken from many residences, and therefore the actual variations for a particular home would be greater than shown. However, the curves can be used as a guide to estimate the amount of variation to expect.

Decide if you are an average or high energy consumer, then use the appropriate curve to help you estimate your peak load.

Variations of load (kW) during the year will follow the same pattern as variations of energy consumption (kW.h) that are discussed under the heading "Monthly Energy Consumption Variations".

Annual Energy Consumption

The average annual energy (kW.h) you would expect to consume can be estimated in several ways:

(a) using values of Average Annual Energy per Year given for appliances in Table 3.3,
(b) using values of Annual Consumption given in Table 3.6, or
(c) converting your present fuel consumption (diesel, propane or furnace oil) to the equivalent kW.h of electricity.

If you have records of your fuel consumption over the past year, the last method will give you the best estimate of the kW.h you would use if you were to convert any of your fuel sources of energy to electricity. The factors for converting diesel fuel, propane and furnace oil to the equivalent electrial consumption in kW.h are given below:

Fuel	Units	To Convert Fuel Used to kW.h multiply by:
Diesel Oil	Litres	3.23
(Diesel Generated Electricity)	Imp. Gal.	14.7
Furnace Oil	Litres	6.03
(Heating)	Imp. Gal.	27.4
Propane (Heating)	Cubic Foot	0.488

(Assumed efficiencies: diesel-electric 30 percent; oil furnace 50 percent; propane furnace 65 percent.) However diesel efficiency could be lower with a lightly loaded or badly maintained machine.

Before deciding to convert heating fuel energy to electricity, read Section 3.3 on the economics of conversion.

The typical annual electricity consumption values shown in Table 3.6 can be used to check your estimates made by other methods.

Item 1 in Table 3.6 gives typical electricity consumption for lighting and appliances for a year for a single-family residence, assuming that water and space heating are provided by other sources of energy (e.g. propane, oil, wood). Item 2 gives typical annual electrical consumption for lighting, appliances and electric water heating.

Item 3 gives typical annual electrical consumption for electrical space heating only: that means you must add this to the electrical consumption for lighting, appliances and water heating, if applicable. Space heating consumption varies with the insulation in the house. Four levels of insulation and energy efficiency are given in Table 3.6. Electricity consumption is given in kW.h per m^2 per 1000 Degree-Days (Celcius) of outside temperatures below 18°C. To calculate kW.h per year multiply the value of kW.h/m^2/1000 DD by the floor area (in m^2) and the average degree days, as listed in Table 3.6 for the city that is nearest to you

Note the difference in consumption between an older house built to standards generally acceptable before 1960 (31 kW.h/m^2/1000 DD), and a Super Insulated house (8 kW.h/m^2/1000 DD -- that's a reduction of 74%). You might want to consider increasing the insulation in your house: you could get information on Energy Efficient Homes from B.C. Hydro's Energy Conservation Division or from Energy, Mines and Resources Canada.

Here is an example of how to estimate your annual electrical consumption:

A single family residence; electric lights, appliances, water heating and space heating; built to Double E Standards; 140 m^2 floor area; near Nelson, B.C. (3734 DD (C)). (Double E is a modern well insulated house incorporating 2" x 6" construction with R20 walls and R40 ceiling.)

	Annual Average Electricity Consumption	
	Example	Your Values
Electric lights, appliances and water heating (Table 3.6, Item 2)	110 x 140 = 15,400 kW.h	....
Space heating (Table 3.6, Item 3c)	$\frac{12x3734x140}{1000}$ = 6,400 kW.h	....
Total	21,800 kW.h	....

Monthly Energy Consumption Variations

The pattern of monthly energy consumption (kW.h) varies with the climate of B.C. Figure 3.2 illustrates this. The curves are based on total electricity consumption in remote communities served by B.C. Hydro diesel plants. The electricity consumption of an individual residence would vary more than is shown for a whole community. However, these curves provide a guide to the minimum variation of consumption to expect in an individual residence.

Example:

A residence in the northern interior of B.C. with an average annual electricity consumption of 20,000 kW.h, including electric space heating.

Mean Monthly Consumption $= \frac{20,000}{12} = 1667$ kW.h

From Figure 3.2, Curve A:

Maximum Monthly Consumption (Dec.) $= \frac{154}{100} \times 1667 = 2570$ kW.h

Minimum Monthly Consumption (July) $= \frac{69}{100} \times 1667 = 1150$ kW.h

You will need electricity consumption values when you are sizing your hydro plant (Section 3.5). You will want to know how much energy to produce at different times of the year, and whether you have to supplement the hydro energy with diesel energy in some months.

3.2.3 Groups of Residences

If there is a group of residences (separate buildings) connected to the hydro plant, the maximum combined load (kW) will be less than the sum of the maximum loads of each residence because the maximum individual loads will likely occur at different times during the day.

To estimate the maximum load on the hydro plant you can use the factors given in Table 3.7.

Example:

Five separate residences are connected to one hydro plant; maximum loads in the residences are estimated to be 5.0 kW, 6.0 kW, 6.0 kW, 9.0 kW and 12.0 kW.

From Table 3.7:

Coincidence Factor for Peak Load for 5 Residences = 0.57
Maximum Combined Load = (5+6+6+9+12) x 0.57 = 22 kW

3.2.4 Motels

Typical electric loads for motels and lodges are given in Table 3.8. Although these data were derived from only seven motels, they can be used to make preliminary estimates of electric loads. The annual energy consumption is given in kW.h per square metre per degree-day (°C) of outside temperature below 18°C.

Example:

A 10 unit motel on the Alaska Highway near Fort Nelson (7087 DD C), total floor area 250 m^2, built in 1980, double glazing, R20 wall insulation.

Maximum Load: (0.06 x 250) to (0.16 x 250)
= 15 to 40 kW

Annual Energy Consumption: $\frac{(50 \times 250 \times 7087)}{1000}$ to $\frac{(160 \times 250 \times 7087)}{1000}$

= 88,600 to 283,000 kW.h

Values that should be used for this example for preliminary feasibility are:

Maximum load - for the cold northern climate an above average value should be selected: Use 25 kW.

Annual electricity consumption - referring back to Table 3.6, the insulation level in the motel is equivalent to Double E standard, so that electricity consumption would be low: Use 90,000 kW.h/year.

3.2.5 Camps

Suggested preliminary estimates of camp loads are given in Table 3.8 (second part) as kW per person in camp. The values are based on data from six camps varying in size from 20 to 750 people, and covering most climatic regions of B.C.

For well insulated and well built units in all areas except northern B.C. use Average values. For units that are poorly insulated, or for units in northern climates use values closer to High values.

3.3 LOAD PLANNING AND MANAGEMENT

In this section we will discuss

Electronic load management
Energy storage
Substitution of fuel (oil, propane) with hydroelectric energy
Parallel generation or hydro and diesel

3.3.1 Electronic Load Management

Three types of electronic load management are described:

Shedding peak load
Using power efficiently
Load control governing

Peak Shedding

In the examples in Chapter 1, Section 1.2.1, we showed that the peak load for the day could be reduced by automatically turning off some of the interruptable loads at about 6 pm (see Figure 1.1). This is called peak shedding: interruptable loads are shed at the time of the peak in the demand (uncontrolled) loads.

At the planning stage (which is where you are now) peak shedding can be used to reduce the size of the hydro plant. Once the plant is built, there is a maximum limit to its output. Then, peak shedding can be used to prevent overloading of the plant.

Using Your Hydro Power Efficiently

Once you have decided on the size of your hydro plant you will want to use as much of its energy as you can: the cost of producing energy will be fixed, and you will not pay more if you use more energy.

Load management enables you to turn on the most useful loads first, and to turn them off last after less useful loads have been turned off. Each controlled or interruptable load is given a priority for automatic on and off switch. Demand loads are not controlled by the load management equipment, so power is available whenever demand loads are turned on.

With load management you can add interruptable loads after the plant has been installed.

Example:

> You could size the plant for the demand loads plus 10 percent to 15 percent for future expansion. If, after a year or two you are not using all the power available, you could convert any fuel-burner heating to electric heating, and retain the fuel-burner furnace as a back-up.

Load Control Governing

Governing controls the speed of the turbine and generator so that the frequency is kept very close to the standard 60 hertz (Hz).

With a mechanical governor attached to the turbine, the water (power) input to the turbine is controlled to balance the electric load on the generator. With electronic load control governing, the electric load is controlled to balance a constant water input to the turbine. There are also hybrid governors where electronic sensing activates mechanical controls.

Mechanical governors are discussed in Chapter 4; here we discuss how electronic load control governing works.

Load control governing is an extension of load management. For governing, we usually need to add a fifth load category to those listed in Section 3.2.2.:

> Waste Load
>
> A load that does not have any use except to control the total load on the generator when all other useful loads are on. For instance, dump space heaters, water heaters, outside air heaters.

Example:

> Consider the 3 bedroom house in Section 3.2.2, shown in Tables 3.1 and 3.5. Table 3.5 shows a daily log for a house without automatic load control. For this example assume that a hydro plant with a capacity of 10 kW is installed with electronic governing.
>
> Between 5 pm and 6 pm the total demand load is 2.8 kW, which is a combination of lights, T.V., kitchen and table saw. Since the generator would be running at full capacity (10 kW) 7.2 kW of controlled loads would also be needed: these are 6.0 kW for baseboard space heating in the house, 0.9 kW for fridge and freezer, and 0.3 kW of waste load, which could be a heater in the greenhouse. Thermostats on the baseboard heaters in the house limit their load to 6.0 kW at this time, and the hot water heater is turned off because the water is up to it's maximum temperature; that's why the waste load is on.
>
> When the table saw is turned off, 1.0 kW load is lost, and a frequency monitor senses an increase in frequency caused by the decrease in load. The waste load is immediately increased by 1.0 kW to 1.3 kW, to bring the total load up to 10 kW again.
>
> If this house had a 10 kW hydro plant supplying power, any load greater than 10 kW would be reduced automatically.

Normally, electrical loads are either off or on: when on, they draw their full rated power (kW). However, for governing with load control, one or more loads must be able to be varied gradually so that the total load is exactly equal to the generator output. This is done with an electronic switch (triac) that can control the electrical wave form to produce a constant frequency of 60 Hz with a varying voltage. A load can be varied continuously over a range from zero to full voltage without changing the frequency.

3.3.2 Energy Storage

Some projects are designed to store energy, in batteries or as water in a reservoir.

If your loads are small, say less than 5 kW, and are not needed all the time, a D.C. generator could be used to charge batteries, for example, at a summer cabin. Technical aspects of the use of D.C. generation and batteries are covered in Chapter 4.

Water storage is discussed later in this Chapter, Section 3.4.4.

3.3.3 Fuel Substitution

If you have fuel sources of energy, such as diesel, propane or oil, you probably want to replace them with hydro power. The decision to do this will be based on economics - a comparison between the costs of burning fuel and the cost of extra energy from your hydro plant.

Three types of fuel substitution are discussed:

Diesel-electric generation
Propane and oil heating
Propane cooking

Diesel-Electric Generation

In many cases replacing a diesel plant with a hydro plant will be economical, but you might want to keep the diesel as a stand-by. This is discussed in Section 3.3.4.

If you have a diesel plant you can compute the cost of electricity per kW.h from the cost of diesel fuel, as follows: (NB: ignoring other costs such as debt retirement, depreciation and maintenance).

Diesel-electric cost per kW.h =

$$\frac{\text{Diesel Fuel Cost in Cents per Gallon (Imperial)}}{14.7}$$

$$\text{Or } \frac{\text{Diesel Fuel Cost in Cents per Litre}}{3.23}$$

Example:

If diesel oil costs \$1.82/gallon (Imperial) or 40 ¢/litre:

$$\text{Diesel-electric Energy Cost} = \frac{1.82 \times 100}{14.7} = 12.4 \text{ ¢/kW.h}$$

$$\text{Or} = \frac{40}{3.23} = 12.4 \text{ ¢/kW.h}$$

To find out if it is economic to replace the diesel with hydro, follow through with calculating the power and energy available from your stream (Section 3.4), sizing your hydro plant (Section 3.5) and making a cost estimate (Section 3.7). Then compare the cost of energy from the hydro plant (Section 3.7.2) with the cost of diesel-electric energy just calculated.

Don't forget that fuel costs are likely to increase every year. To make a fair comparison of costs, you will have to estimate how fuel costs will increase over the next 5 to 10 years. Read Chapter 6 for examples of how to do this.

Propane and Oil Heating

Converting propane and oil heating (fuel burner heating) to electric heating with a hydro plant is often not economical. This is because electric heating loads normally consume a large portion of the total load in a residential situation, such as a house, hotel or camp.

For example, look at Table 3.1, Column #2: the rated load of the baseboard space heating is 10 kW, which is 38 percent of the total load. In this example the hydro plant would be sized to meet the maximum average 24 hour load of 8.85 kW (Column #8), plus about 10 percent for future additional loads: 10 kW will do. If the space heating were left as oil or propane furnace heat, the total of Column #8 would be reduced to 2.6 kW, and the maximum total load would then be 5.6 kW for all demand loads (Columns #5 and #7). A hydro plant of 6 kW to 7 kW would be adequate.

Now compute the cost of energy over the next 5 to 10 years for the two alternatives:

(a) a 10 kW hydro plant.
(b) a 7 kW hydro plant plus oil or propane space heating.

For Alternative (a), remember to add the cost of electric heating equipment.

For Alternative (b) compute the cost of propane or furnace oil which is equivalent to a kW.h of electric heat, as follows:

Propane Cost per kW.h of Electric Heat =

$$\frac{\text{Propane Cost in Cents per Litre of Liquid}}{4.8}$$

$$\text{Or } \frac{\text{Propane Cost in Cents per Cu.Ft. of Gas}}{0.488}$$

(For converting litres of propane liquid to cubic feet of propane gas use 0.1 litre/cu.ft.)

Example:

If propane costs 26 ¢/litre of liquid or 2.66 ¢/cu.ft. of gas

$$\text{Propane Cost per kW.h} = \frac{26}{4.8} = 5.4\ \text{¢/kW.h}$$

$$\text{Or} = \frac{2.66}{0.488} = 5.4\ \text{¢/kW.h}$$

Furnace Oil Cost per kW.h of Electric Heat =

$$\frac{\text{Furnace Oil Cost in Cents per Litre}}{6.0}$$

Or $\frac{\text{Furnace Oil Cost in Cents per Gallon (Imp.)}}{27.5}$

Example:

If furnace oil cost 39.0 ¢/litre:

$$\text{Furnace Oil Cost per kW.h} = \frac{39.0}{6.0} = 6.5\ ¢/\text{kW.h}$$

Remember, these costs are for today's prices. For a proper economic comparison of hydroelectric heating and fuel-burner heating you will have to estimate future costs of fuel. Chapter 6 will help you do this.

In some situations electric heating loads can be added without having to increase the installed capacity of the hydro plant: the electric heating will be free. This is possible if the hydro plant is sized for demand loads, and there is unused off-peak energy available.

Example:

Refer to Table 3.1, in Section 3.2.2. Assume there are no electric space heating loads: the total in Columns #6 and #8 will be 2.45 kW and 2.60 kW. Assume that 3 kW of demand load is added to the workshop load: the totals in Columns #5 and #7 will be 8.6 kW. A 10 kW hydro plant would probably be installed. Now, if the heating load is added, the total for Columns #5 to #8 will be 8.6 kW, 3.28 kW, 8.6 kW and 8.85 kW. The maximum load would be 8.85 kW, and there would be no need to increase the installed capacity of the hydro plant above 10 kW; the space heating energy would be free.

This illustrates the need for a realistic assessment of your future loads. If the situation illustrated in the example above does not apply to you, it might be cheaper to improve the insulation in your building instead of converting propane or oil heating to hydro electric heating.

Propane Cooking

Electric cooking loads are demand loads: they are required at the peak load times, and they are not controlled by load management. Converting propane cooking to electric cooking is less likely to be economic than converting propane or oil heating to electric heating. However, there might be other reasons for wanting to convert from propane to electric: the convenience of having all energy from one source, for example.

To make an economic decision about conversion, compute the cost of propane equivalent to 1 kW.h of electric heating using the conversion factor in the previous section: remember this cost is based on today's prices. Then follow through Sections 3.4 to 3.6 as for previous cases of fuel substitution.

3.3.4 Combined Hydroelectric and Diesel Generation

Many small hydro plants have a diesel plant for a back-up source of electricity. There are several reasons why you might want to have a combined hydro and diesel source of electricity:

(a) You already have a diesel plant and you want to reduce diesel fuel consumption.
(b) You want to build a hydro plant, but

- your stream doesn't have enough water to produce the energy/power you need all year, or
- a hydro plant large enough to produce all the energy/power you need would be uneconomic to build.

For Case 2a) a water storage reservoir could be considered as an alternative to a diesel plant. However, a diesel plant will probably be the cheaper alternative. An economic comparison of these alternatives should be made, as discussed in Section 3.5.

The diesel generator could be used intermittently or continuously; both operations will probably be shown to be economic.

Intermittent Diesel Use:

A diesel generator would be used intermittently if the flow in the stream is too low for a hydro plant to produce sufficient power during dry periods (several weeks) in the summer or very cold periods in winter. This might happen every year, or only in extreme cases about once in five or ten years.

Continuous Diesel Use:

A diesel generator would be used continuously if the flow or head in the stream is insufficient for a hydro plant to produce the power you need at any time; or if a hydro plant large enough to produce all the energy and power you need is uneconomic to build.

For sizing the hydro and diesel plants together, follow through Sections 3.4 and 3.5. When doing this, it is important to consider heating requirements separately: burning fuel (in a furnace) to produce heat directly, is about three times more efficient than using fuel in a diesel plant to produce electricity which is then used for heating. Therefore, when calculating the size of the diesel plant, leave all heating as furnace heat or as hydro: do not use diesel generation for electric heating.

The technical considerations of synchronizing hydro and diesel generation are discussed in Chapter 4.

3.4 POWER AND ENERGY AVAILABILITY

3.4.1 Power Equation

In Chapter 1, Section 1.3.1, the theoretical power equation was given as:

$$P = Q \times H \times e \times 9.81 \text{ kW} \qquad 1\text{-}1$$

The efficiency of the plant "e" was assumed to be 60 percent, including the efficiencies of the turbine, generator, and electricity transmission, and also the head loss in the pipeline, which was assumed to be 10 percent of the gross head. (See Figure 1.2 for definitions of gross head and head loss.)

However, the head loss will probably be less than 10 percent particularly if the length of the pipeline is less than 100 m. If you want a more accurate estimate of the head loss in the pipeline, so that you can get a better estimate of the power output of the plant, use the following power equation.

$$P = Q \times (H_g - H_1) \times e \times 9.81 \text{ kW} \qquad 3\text{-}1$$

Where:

Q = Flow in the pipeline (m^3/s)
Hg = Gross head (see definition sketch Figure 1-2), (m)
h_1 = Head loss in pipeline (m)
e = Efficiency of turbine, generator and transmission, as a decimal

For the efficiency "e", use a typical value of 0.70, or estimate a value from the information given in Chapter 4.

The head loss "h', for plastic pipe can be estimated from the nomograph in Figure 3-3. For steel pipe, use the same nomograph to estimate head loss, then multiply the head loss by 1.23.

Examples of the use of Figure 3.3:

(a) Find the head loss for 200 m of plastic pipe for a discharge of 0.6 m^3/s (600 L/s). Assume the velocity in the pipe is 2 m/s.

Figure 3.3:

Draw a line between values on the Discharge (Flow) and Velocity scales as follows:

Discharge = 600 L/s
Velocity = 2 m/s

This line intersects the Pipe Diameter and Friction Head Loss scales at:

Pipe Diameter = 630 mm
Friction Head Loss = 0.66 m per 100 m length of pipe.

Head loss for 200 m of plastic pipe $= 0.66 \times \frac{200}{100} = 1.32$ m

(b) Find the head loss for 500 m length of 250 mm diameter steel pipe, for a discharge of 100 L/s.

Figure 3.3:

Draw a line between the Discharge (Flow) and Pipe Diameter Scales as follows:

Discharge = 100 L/s
Pipe Diameter = 250 mm

Extend this line to the Friction Head Loss and Velocity scales and read off:

Friction Head Loss = 1.55 m per 100 m length of pipe
Velocity = 2 m/s

Head loss in 500 m of steel pipe $= 1.55 \times \frac{500}{100} \times 1.23 = 9.5$ m

The term $(Hg - H_1)$ in equation 3-1 is called the Net Head (Hn): the net head operates on the turbine to produce power (see the head definition sketch in Figure 1.2). The power equation can be rewritten as:

$$P = Q \times Hn \times e \times 9.81 \text{ kW} \qquad 3\text{-}2$$

The efficiency "e", as in equation 3-1, is the efficiency of the mechanical and electrical equipment that converts water power to electricity. This efficiency would typically be between 67 percent and 72 percent. Using a value of 70 percent, the power equation is:

$$P = Q \times Hn \times 6.9 \text{ kW} \qquad 3\text{-}3$$

The turbine manufacturer needs the net head to design the turbine. However, it is the gross head (Hg) that you actually measure in the field; the gross head is the difference between the elevation of the intake and the turbine. You have to calculate the head loss to get the net head.

Be aware of the difference between gross and net heads when you are reading the remainder of this manual.

3.4.2 Flow Availability

In Chapter 1 you estimated the lowest flow expected in the stream: probably, that estimate was ot very accurate. In Chapter 2 your were asked to build a weir in the stream, install a gauge, and measure the flow every day.

By now you should have several weeks or months of daily streamflows so you can make more reliable estimates of the flow and power available from the stream.

The streamflows that have to be estimated, are

(a) The lowest flow to expect in the future: from this you can calculate the size (kW) of a hydro plant that will supply power throughout the year.

(b) the magnitude of low flows, and the duration of the low-flow periods. The low flow periods you would check are:

- during the winter (December to March) when the loads are high and the flows are low due to cold weather and little rain;
- during the summer (July to October) when flows are normally the lowest in the year, but often the loads are low also.

From these flow data you can estimate when there is insufficient flow to generate the power you need. From this you can calculate

1. the amount of supplementary diesel-generated electricity needed, or
2. The' amount of supplementary oil or propane heating needed, or
3. The size of a storage reservoir, and height of the storage dam.

(3) The peak flows for the sizing of a spillway.

A Flow-Duration Curve can be used to make most of these estimates; and a Mass Curve can be used to determine the appropriate size of storage reservoir. These two methods are discussed in Sections 3.4.3 and 3.4.4.

3.4.3 Flow-Duration Curve

A flow-duration curve is a convenient way of representing the variations of flow in a stream over a period of several years. (The method of plotting a flow-duration curve is explained in Supplement 3.1 at the end of this Chapter.

A typical flow-duration curve is shown in Figure 3.4. It is a plot of flow (vertical axis) versus the percent of time that particular flow is expected to be exceeded (called "percent exceedance", on the horizontal scale).

In Figure 3.4 for example, 54 percent of the time you can expect the flow to be greater than 0.54 m^3/s; 95 percent of the time greater than 0.23 m^3/s, and 100 percent of the time greater than 0.11 m^3/s, which is the lowest flow recorded in this stream.

If there is no permanent stream gauge on your stream, you can construct a flow-duration curve by plotting a flow-duration curve for a nearby stream that does have a gauge. Adjust the "flow" scale to apply to your stream, using the flows you have measured at your weir. (The method is explained in Supplement 3.1.)

In this way, you can create a flow-duration curve to estimate the expected flow characteristics of your stream using the small amount of flow data you have measured.

Before you start to construct the flow-duration curve, ask the nearest Water Management Branch office for any flow-duration data for streams near your stream: the Branch might have a computer program to do this.

If you don't have enough time or you don't feel confident enough to construct a flow-duration curve, you could ask an engineer to calculate how much power is available in your stream. The engineer might use other methods which could give more reliable results.

Use of Flow-Duration Curve

(a) Expected Low Flows

On a Flow-Duration Curve, the lowest expected flow will be exceeded 100 percent of the time: this is 0.11 m^3/s on Figure 3.4. Notice, on Figure 3.4, that the 95 percent exceedance flow is 0.23 m^3/s, which is twice the lowest flow. This is typical for most streams: there is normally a sharp drop in the flow-duration curve for exceedance greater than 95 percent to 97 percent.

If the lowest flow would not produce enough power to meet your load throughout the year, use the 95 percent exceedance flow (Q95). The flow in the stream would be lower than this Q95 value only 5 percent of the time, or 18 days each year.

However, the flow duration curve does not show you when these low flows occur. They would probably occur in the summer when the load is low, but they might occur in the winter when the load is high. In that case you might need supplementary energy. To check the magnitude of the flows at the time of the highest load, say, December to January, you would draw a flow duration curve for those two months only as explained in Supplement 3.1, Section 1.2. You would then calculate the amount of supplementary energy needed, as explained next.

There is more discussion on selecting flows for sizing your plant in Section 3.5, and Supplement 3.1.

(b) Supplementary Energy Requirements

If the flow in the stream is not sufficient to generate the power you need, the amount of supplementary energy that has to be generated from diesel can be calculated from the flow-duration curve.

Example:

Suppose the maximum turbine-generator output is 15 kW and the net head (Hn) is 4.0 m: the flow required would be (from equation 3-3):

$$Q = \frac{P}{Hn \times 6.9} = \frac{15}{4.0 \times 6.9} = 0.54\ m^3/s$$

In Figure 3-4, the flow will be greater than 0.54 m^3/s 54 percent of the time, as shown by the flow-duration curve above Point B; the rest of the time the flow will be less than 0.54 m^3/s, as shown by the flow-duration curve BC. The area ABCDE below the flow-duration curve and the remaining area below a horizontal line through 0.54 m^3/s, represents the average flow available for power during the year. See Supplement 3.1, Section 3.1, to find out how to calculate the area under the flow duration curve.

The average energy available in a year is:

Area ABCDE x Hn x 6.9 x 8760 kW.h

if: ABCDE = 0.44m^3
Hn = 4.0 m
Available Energy = 106400 kW.h

If you know how much energy you use in a year, or if you can estimate it, subtract from it the energy available from the stream (just calculated) to get the supplementary energy required from the diesel plant.

Alternatively, if you want to check that energy is available during the high load period in December and January, draw a flow duration curve for this period (Supplement 3.1, Section 1.2 explains how). To illustrate how to use the curve assume, now, that the curve in Figure 3.2 represents the flow duration curve for December and January only. If the maximum turbine-generator output is 15 kW, the maximum flow required is 0.54 m^3/s.

The energy deficiency during the two months, or 62 days, in December and January is:

Area BFC x 62 x 24 x Hn x 6.9 kW.h

if: BFC represents an average flow = $0.07m^3$
Hn = 4.0 m
Energy deficiency in December & January = 2,900 kW.h

3.4.4 Reservoir Storage and the Mass Curve

If you need storage, or if you want to consider storage as an alternative to a diesel plant for generating supplementary energy, you can calculate the size of the storage reservoir by using a mass curve.

However, as the procedure involves a lot of calculations, a description of the construction and use of the mass curve has been put into Supplement 3.2, at the end of this chapter.

3.5 SMALL HYDRO PLANT SIZING

The next step is to match the size of your hydro plant to the power and energy available in the stream.

If the flow in the stream will always be large enough to produce the power you need year round, the procedure for selecting the size of the turbine and generator and the layout of the project will be straight forward. Often, however, the flow in the stream, or the available head, is not large enough to produce the power you need: in this case the procedure for sizing the plant becomes more involved. Both these cases are covered in Section 3.5.2.

This section covers

(a) variables and options in sizing a hydro plant,
(b) procedure for sizing a hydro plant when the load is known,
(c) a simplified procedure for sizing a hydro plant when the load is known,
(d) a procedure for sizing a hydro plant when the load is not fixed.

3.5.1 Variables and Options

Variables

Most of the factors considered in sizing a hydro plant are variable:

Loads vary throughout the year, and load management affects the amount of this variation. Most loads are high in the winter and low in the summer.

Flows vary throughout the year. On the coast, flows are high in winter, low in late summer; in the interior flows are low in winter and high in May through July (see the hydrographs in Figure 1.4A and B). Do the variations in flow coincide with the variations in load?

Head: values can vary for a particular stream.

Turbine Power Output: varies with the flow available for a particular head. (See Chapter 4 for a discussion of turbine characteristics).

When sizing the turbine and generator, these are the variables for which you have to select values.

Options

Power from the Hydro Plant

Two different situations are considered:

(a) The load is known, and the hydro plant must be able to meet the load.

(b) The load is not known, and you want to know how much power and energy can be generated by the hydro plant; you want to know how large a camp, sawmill, hotel, or community can be supplied.

Supplementary Power from Diesel or Storage

If the flow in the stream, or the head, is not large enough to produce all the power you need, there are two options:

(a) Use a diesel for supplementary power.
(b) Build a storage dam.
(c) For very small systems you could use battery storage.

Normally, with small hydro plants, using diesel is more economic than building a storage dam. The selection between these options is covered in the procedures in Sections 3.5.2 and 3.5.3.

Low Head Hydro Plants

The procedures in Section 3.5.2 and 3.5.3 for sizing your hydro plant apply to plants in which the head does not change with a change in flow.

In a low-head plant, with a head less than about 10 m, the forebay level (upstream of the intake) and the tailwater level (downstream of the turbine) often change when the flow changes; this in turn changes the head and the power output of the turbine.

If you are planning a low-head plant, you will have to estimate the variations in forebay and tailwater levels, to arrive at the correct head for the power calculations in the sizing procedures. You should read Chapter 8 on Low-Head Plant Considerations.

3.5.2 Procedure for Sizing Your Plant for a Known Load

An outline of the procedure for sizing a hydro plant is given in Table 3.9. As part of this procedure you will have to read Section

3.6, Preliminary Arrangements of Structures and Selection of Equipment, and Section 3.7, Project Costs. A discussion of some of the steps in that procedure is given below.

Don't be put off by the number of steps in Table 3.9; they cover most of the things you have to do in planning a hydro project, and many of these things you've done already. The steps have been put together here in the form of a guide or check list, and in a convenient form for discussion.

In Section 3.5.3 a simplified procedure is suggested for the person who does not want to follow all the steps outlined in Table 3.9.

The following discussion refers to the Step Numbers given in Table 3.9.

Steps 1 - 3 (Load Estimates) and Step 7 (Plant Capacity)

Your load inventory in Section 3.2.2 will give you the loads. You can estimate the seasonal variations from the information in that same section. Check Section 3.3.1 (Electronic Load Management) and Section 3.3.3 (Fuel Substitution, Propane and Oil Heating, and Propane Cooking) for any information that applies to your loads.

If you have a residential load and plan to use electronic load management, you should calculate the following expected loads:

(a) Peak Demand Load in Winter - not including Interruptable Loads;
(b) Average 24 Hour Load in Winter - all loads except Fully Interruptable Loads;
(c) Peak Demand Load in Summer - not including Interruptable Loads;
(d) Average 24 Hour Load in Summer - all loads except Fully Interruptable Loads.

The largest of these four loads should be considered as the minimum size of plant that you need. Add to this about 10 percent, or whatever you think appropriate to allow for future growth. This will give you the initial Plant Capacity (P_1) for Step 7. Follow through to Step 11.

Now check to see if you can justify the additional expense to convert any Fully Interruptable Loads to the hydro electric source. Calculate the following loads, including all Fully Interruptable Loads:

Average 24 hour load for all loads in winter
Average 24 hour load for all loads in summer

If the loads in 5 or 6 are larger than in 1 to 4 above, use the largest load (plus an allowance for future growth) for the Plant Capacity (P_1). Repeat Steps 8 to 11 with the larger load. Then decide whether or not to convert Fully Interruptable Loads to hydro.

Steps 4 and 8 (Minimum Flow)

If the minimum flow is zero, use the flow expected 95 percent of the time (if you have drawn a flow-duration curve) or, for the Simplified Procedure, use the flow for the month prior to the month with zero flow; then go to Step 17.

Step 8

If you do not think that the assumptions made about efficiencies and headloss in the Power Equation 1-2 (Chapter 1) apply to your project, you can use the revised Power Equation 3-3 (Section 3.4.1), with e = 0.7 to find the gross head H:

$$Hg = \frac{P_1}{Q_{min} \times 6.9} + H_1$$

Step 18 (Head Suitable for Site)

Find the steepest section of the stream within about 1 km of your load. Then measure the slope of the stream upstream and downstream of this steep section: if the slope is less than about 10 percent or 6 degress to the horizontal for any significant length it probably won't be worth putting in a pipeline to get extra head.

Steps 19 and 20 (Use of Flow-Duration Curve)

See Supplement 3.1, Section 3.0, for calculating the average energy available when the minimum turbine flow is not available 100 percent of the time.

Step 25 (Total Cost of Energy from Hydro and Diesel)n

Total cost of energy per kW.h equals:

(Annual Energy from Hydro (kW.h) x Cost of Hydro Energy (¢/kW.h) plus (Average Annual Energy from Diesel (kW.h) x Cost of Diesel Energy (¢/kW.h)) divided by Total Energy from Hydro and Diesel.

Step 27 (Reservoir Storage)

Consider seeking advice from an engineer to calculate the amount of storage you need. You will probably need an engineer to design any storage dam higher than 2.0 m.

Step 28 (Mass Curve)

Supplement 3.2 explains how to construct and use a Mass Curve to estimate the storage volume and depth that are required.

To allow for the rise in water level during floods, the height of the dam should be about 1.0 m higher than the depth of storage required. An engineer would be able to tell you how high the dam should be.

Steps 34 and 36 (Use of Flows Other Than the Minimum Flow to Size the Plant)

See Supplement 3.1 for an explanation of how to use the flow-duration curve to size the turbine and to calculate the average annual energy available when using flows greater than the minimum flow.

3.5.3 Simplified Procedure for Sizing Your Hydro Plant for a Known Load

You might choose to use the Simplified Procedure if you believe the layout of your hydro project to be obvious, based on your knowledge of the stream and several years observation of its flows, and your knowledge of the site.

In these cases you could plan the project that best suits the stream, estimate the power and energy, estimate the cost, and check that you can pay off this cost in about five years. Then, a year or two later, based on the performance of the hydro project, you could decide if you should add another turbine. You could use the Simplified Procedure as a checklist of things to do.

Simplified Procedure

Use Table 3.9, but only do the Steps marked with an asterisk. These steps are listed below:

Steps 1 to 3

Step 4

Estimate the minimum flow from your observations over several years, or from records on a nearby gauged stream (as explained in Chapter 1, near the end of Section 1.4.1).

Steps 7 and 8

Step 9

If the site is suitable for the head computed in Step 8, do Steps 10, 11 and 12, 13 and 15, then estimate the annual energy from your load inventory (21), and using 13 and 21 compute your total cost of energy.

If the site is unsuitable for the head computed in Step 8, do Steps 17 to 26.

3.5.4 Procedure for Sizing a Hydro Plant for an Undetermined Load

Use this procedure if you want to build a plant that will produce the maximum energy from the stream at least cost. If your investment in the project is large, it will be worth hiring an engineer to select the optimum plant size and to advise on other aspects of the design.

The following procedure is one you could use yourself. You need to compare the cost of energy from several different sized plants, then select the plant with the lowest energy cost.

Use Table 3.9, but do only the steps listed below:

Steps 1 to 6 (Table 3.9)

Step 7a (New Step for Selecting Plant Capacity)

Refer to Appendix I for an explanation of the following calculations. From the flow-duration curve select the flow with 15 percent exceedance; make the turbine design flow equal to this flow; compute the turbine minimum flow as 50 percent of the design flow.

Step 8a (New Step)

Select the maximum practical head for the site.

Steps 10 to 13 (Table 3.9)

Compute the cost of energy (¢/kW.h).

Repeat Steps 7a to 13 Several Times with Different Flows

Use the 20 percent, 30 percent and 50 percent exceedance flows for the turbine design flow; use the same head as in Step 8a each time; select the alternative with the lowest energy cost; go to Section 3.8.

Repeat Steps 7a to 13 with Different Heads

For the flow with the lowest energy cost found in the previous steps, select several alternative gross heads and repeat Steps 7a to 13. Select the alternative with the lowest energy cost, then go to Section 3.8.

3.5.5 Selection of the Best Layout

The previous sections suggested that the plant size and layout with the lowest energy cost should be selected for further study. However, don't overlook the practicality of the construction and operation of the lowest energy cost plant. It might be worth spending extra money for a plant size and layout that you feel will be easier to build, and be less problematic to operate.

Consideration about the lowest energy cost alternative are:

Construction:

(a) access: Might access to the pipeline and intake be difficult? Is there a different layout that would have easier access?

(b) storage reservoir: Could you eliminate the storage reservoirs it is probably the most expensive part of the project.

(c) pipeline: Is the terrain hard to build on: for example, are there steep side slopes, rock-outcrops, bogs? Is there another longer route that might be easier for construction?

(d) foundations: Are you sure there is firm ground for foundations at the intake dam and powerhouse sites? Would you be sure of better foundations at different sites?

Operation:

(a) blockage of intake: Do you expect the intake will often be blocked by debris? Is there a different location less susceptible to blockage?

(b) icing-up at intake or in the pipe: Is there a better layout that will reduce the probability of icing? Would a deeper headpond (higher intake dam) prevent icing at the intake? Would burying the pipe prevent icing-up?

(c) damage to pipeline: Is the pipeline exposed to possible damage from falling trees or rocks, or to possible damage at road and stream crossings? Would the pipeline be safer buried, or better protected road and stream crossings?

3.6 PRELIMINARY ARRANGEMENT OF STRUCTURES AND SELECTION OF EQUIPMENT

Now is the time to review the initial project layout which you made in Chapter 1, and revise it if necessary. This will enable you to make a better estimate of the cost of the project, and to decide whether or not to continue with the final design and construction.

You have the following new information since Chapter 1:

(a) a better knowledge of the site, after making the explorations suggested in Chapter 2; and

(b) a more accurate estimate of the size of the plant you should build (from calculations in Sections 3.5.2, 3.5.3 or 3.5.4).

Review the general information on project layouts and structures given in Chapter 1, Sections 1.5.2 and 1.5.3; also, review the guide for selecting good sites for the structures, given in Chapter 2, Section 2.6. Check if there are any alternative types of structures that might suit the site better than the structures in your initial layout.

If you feel you need more technical details, refer to Chapter 4. But remember, at this stage you are preparing the layout of the structures and calculating their overall dimensions so that you can make a cost estimate; the final design of the structures comes later.

If you have not already done so, calculate the plant capacity using Equation 3-1 which gives the turbine-generator efficiency and the pipeline headlosses separately. This will enable you to make a more accurate estimate of the plant capacity. Efficiencies for different turbines, generators, and mechanical transmission, as well as co-efficients for head-loss in pipes, are given in Chapter 4.

3.7 PROJECT COSTS

3.7.1 Capital Costs

The cost estimates you make here will be more reliable than the ones you made in Chapter 1. You now have better information about the site, your loads, and the power plant size; and you will be able to make a more detailed cost estimate using the cost curves in Figures 3.5 to 3.11.

The list of items to be costed is the same as in Chapter 1, Section 1.8.1.

If you are considering buying used equipment or materials -- and saving 50 percent or more on new items -- read the note in Chapter 1, Section 1.8.1. Start making enquiries about what equipment or materials are available, and find out the approximate costs for use in this Section.

Clearing and Access

The comments in Section 1.8.1 still apply; the best estimate for clearing and access would be a price from a local contractor, logging company or cat owner.

Storage Dam

Because the failure of a dam, and the resulting release of water could cause sever damage or loss of life, there are strict criteria for the design of dams and spillways. A storage dam should be designed by an engineer. However, before you get an engineer to design the dam, you might want to know the approximate cost of the dam, for comparing alternatives for supplying supplementary energy (Sections 3.5.2 and 3.5.3). Figure 3.5 has been prepared for this purpose. An earthfill dam is shown as an example but other types of dams could be used as storage dams. Figure 3.5 shows the cost of an earthfill dam per length of dam crest versus dam height, and the cost of the outlet works versus dam height.

To Estimate the Cost of the Dam:

1. Make a sketch of the ground at the damsite along the length of the dam (as in Figure 3.5).
2. Draw the crest of the dam at the height calculated (Step 28 of Table 3.9).

3. Divide the length into 3 to 5 sections so that each section can be represented by an average height (e.g. h_1 to h_4 in Figure 3.5).
4. Multiply the cost of each average height by the length of its section (e.g. L_1 to L_4).
5. Add the costs of all the sections.
6. Read from Figure 3.5 the cost of the outlet works for the maximum dam height.
7. Add the cost of the outlet works to the earthfill cost. To allow for the cost of the spillway add 15% of the total cost of the dams.

Intake Weir

Cost curves for a concrete weir (Figure 3.6) and a gabion weir (Figure 3.7) are given as alternatives.

Concrete Weir:

In Figure 3.6, Scale A, the unit cost of concrete is $200/m^3, the price you would pay to a contractor to build the weir. This price is for concrete mixed at site or delivered from a mixing plant (at $100/m^3) and it includes simple formwork and nominal reinforcing steel needed for a concrete dam. The cost of excavation is included in the curve in Figure 3.6.

If you plan to build the weir yourself, use non-union labour, or mix the concrete at site, the unit cost of concrete will be less than $200/m^3. Estimate your unit cost of concrete, but remember to include the cost of the formwork, reinforcing steel and labour. Then use Figure 3.6, Scale B, to find the volume of concrete to be multiplied by your unit cost.

Example:

1. Unit cost of concrete $100/m^3, including formwork, reinforcing steel and labour.
2. Make a sketch of the concrete weir with the existing ground line, divide the length into about five sections and find the average height of each section, as described for the earthfill storage dam.
3. For each section height read from Figure 3.6, Scale B, the volume of concrete required per metre length of section.
4. Multiply this volume by $100 to find the unit cost of concrete per metre length of section.

5. Multiply this unit cost by the length of the section (i.e. L_1, L_2 etc.) to find the cost of the section.

6. Add the cost of all sections to find the cost of the weir.

Gabion Weir:

The cost curves given on Figure 3.7 are based on the following assumptions:

Gabions filled by hand (union labour rates) - $100/m^3 (Scale A);
Excavation, 0.5 m deep - $6/m^3 (Scale C);
Seepage control fill - $6/m^3 (Scale C);
Watertight membrane, installed cost - $3/m^2 (Scale C).

These are the prices you would have to pay to a contractor to build the gabion weir.

If you plan to use non-union labour to fill the gabions, and if rock for filling the gabions can be moved to site with a small front-end loader (i.e. you don't have to pay for rock to be delivered), the cost of placing and filling the gabions could be as low as $60/m^3.

If you want to make your own estimate of the cost of building the gabions use the formula:

> Cost of Gabions per Metre Length of Weir = $60 + Cost of Labour per Hour

Example:

Cost of labour $12/hour. Rocks to be moved to weir site by front-end loader.

1. Make a sketch of the gabion weir with the existing ground line; divide the length into about five sections, find the average height of each section; all as described for the earthfill storage dam.

2. Read from Figure 3.7, Scale C, the additional costs of excavation, upstream fill and membrane, in $ per metre length of each section height.

3. Multiply this volume by ($60 + $12) = $72 to calculate the cost of gabions in each section.

4. Add the cost of gabions per metre length (Item 3) and the additional costs per metre length (Item 4), and multiply by the length of the section (i.e. L_1, L_2 or L_3, etc.) to find the cost of each section.

5. Add the costs of all sections (Item 5) to find the total cost of the gabion weir.

General note: The cost of relatively small quantities of materials could be higher than shown. Also add allowances, if required, for transportation costs and living expenses.

Pipeline Intake

The curves in Figure 3.8 show the intake cost and concrete volume for a free-standing intake (used with a gabion dam) and for an intake which is part of a concrete dam.

The unit cost of concrete used in Figure 3.8, Scale A is \$400 per m^3. This is the price you would pay to a contractor to build the intake. This price is for concrete mixed at site or delivered from a mixing plant, and includes the complicated formwork and reinforcing steel necessary for the intake structure.

If you think that your concrete unit cost will be less than \$400/m^3, make your own estimate, but remember to include the cost of the complicated formwork and the reinforcing steel. These costs will be \$150/m^3 even if you are only paying \$12/hour for labour.

To find the cost of the intake:

1. Select the pipeline diameter.
2. Find the minimum height of the intake required to prevent vortices (Figure 3.8, Scale D).
3. Estimate the actual height of the intake - the headpond might be deeper than the minimum height required in Item 2.
4. Find the cost of the intake for the selected pipe diameter and type of intake, using Figure 3.8, Scale A.
5. Or, find the volume of concrete in the intake (use Figure 3.8) and multiply the volume by your estimated unit cost of concrete per m^3.
6. Add the cost of the trashracks from Figure 3.8, Scale C.

Pipeline

Make a sketch of the pipeline route and mark a few ground elevations and lengths along the pipeline to define the profile (as shown in Sketch A in Figure 3.9, EL. 10 m, EL. 20 m, EL. 30 m, etc. and L_1, L_2, L_3, etc.). This will enable you to estimate the head on various sections of the pipeline, (as shown in Sketch B) and to choose the correct cost for each section. This applies to polyethylene plastic pipes only. except where the head is too high for plastic pipe and steel pipe must be used.

Select the pipe diameter from the nomograph in Figure 3.3. Use the design flow that you used for sizing the plant in Section 3.5, and assume a pipe velocity of 2 m/s. Draw a straight line between the design flow on the Discharge scale and a velocity of 2 m/s on the Velocity scale. Where this line intersects the Pipe Diameter scale, read off the diameter in millimetres.

Turn to the table on Figure 3.9. Column #1 shows a Pipe Classification which corresponds to a range of Gross Head (or pressure head) in Column #2. Each classification of pipe can withstand a pressure head equal to the maximum in the range in Column #2, for example, "A" pipe can withstand a gross head up to 31.6 m, "B" pipe a gross head up to 42.2 m. This classification is for polyethylene pipe only; steel pipe is strong enough to withstand a gross head in excess of 150 m.

For costing polyethylene pipe, mark off the maximum gross head in each classification on your sketch of the pipeline, starting from the intake, as in Sketch B, Figure 3.9. Then measure the length of each classification of pipe, for example, LA, LB, LC in Sketch B.

For each classification, read from the table on Figure 3.9 the cost per metre of pipe under the appropriate pipe diameter; multiply that unit cost by the length for that classification to give the cost of that section of pipe.

Example:

Pipe diameter - 500 mm.

Draw up a table as shown below. The lengths LA, LB, etc. are taken from your sketch, similar to Figure 3.9, Sketch B. The unit costs of pipe per metre are taken from the table on Figure 3.9.

Pipe Classification	Length m	Unit Cost $/m	Cost of Section $
A	LA = 50	155	7750
B	LB = 10	205	2050
C	LC = 20	265	5300
D	LD = 13	324	4212
E	LE = 13	518	6734
F	LF = 10	518	5180
Total Cost of Pipeline			$31226

Add the cost of a valve, from the table on Figure 3.9, to get the total cost of the pipeline.

Powerhouse

Figure 3.10 shows cost curves for the powerhouse sub-structure (concrete foundations and floor) and superstructure (wood or prefabricated steel).

For the sub-structure cost you need the rated output of your hydro plant in kW. Use the top graph on Figure 3.10 to find the sub-structure cost.

The superstructure floor area depends on the physical dimensions of the turbine and generator, and its size is related to the penstock diameter. Use the bottom graph on Figure 3.10 to find the cost of the superstructure for the penstock size and type of turbine you have selected.

Add the costs of the sub-structure and superstructure to get the total powerhouse cost.

Turbine-Generator-Electrical Equipment

Figure 3.11 can be used to estimate the cost of the turbine, generator and electrical equipment in the powerhouse. You need to know the net head on the turbine (from Section 3.4.1) and the hydro plant output in kW to find the cost of the equipment.

The cost lines on Figure 3.11 were derived from manufacturers prices for turbines, generators and other electrical control equipment. The lines show average costs and should only be used for initial estimates of equipment costs. When you get quotations for the turbine, generator and other equipment you can expect the costs to vary as much as 40 percent more or 40 percent less than the costs given on Figure 3.11. You will generally get the quality you pay for: low-priced turbines will probably be made of cheaper materials and probably require more repairs than higher priced turbines. Read the section in Chapter 4 for more discussion on quality, repair and expected life.

A very small turbine-generator unit with an output of 1.0 - 1.5 kW, batteries and a battery-charger might be suitable for lights and a few appliances in a small, well-insulated house or a summer cabin. The cost of turbine, generator, load controller/regulator, and inverter would be about:

1.0 kW - $ 9,000
1.5 kW - $13,000

Transmission Lines and Cables

Use the table below to estimate the cost of transmission lines or cables running from the hydro plant to the load. Refer to Chapter 4 for a discussion of voltages and different types and sizes of cables you could use.

Wood Pole Transmission Line:
(3-phase, 2.4 kV, up to 250 kW) $17,000/km

High-Voltage Buried Cable:
(single-phase, up to 85 kW) $15,000/km

(Data to be abstracted from Chapter 4.)

Tailrace Channel

This is usually a minor cost item. However, a cost figure should be included in the estimate. A cost curve cannot be prepared for the tailrace channel because the channel dimensions depend entirely on the site. Make your own estimate for this item or ask for an estimate from the person you talked to about the clearing and access costs.

Contingencies and Engineering Costs

Use the values that were given in Chapter 1, Section 1.8.1.

Summary of Project Costs

List your project costs below:

	$
Clearing and Access	....
Storage Dam	....
Intake Weir	....
Intake Structure	....
Pipeline	....
Turbine, Generator, Electrical Equipment	....
Powerhouse	....
Transmission	....
Tailrace Channel	....
TOTAL COST OF STRUCTURES AND EQUIPMENT (a)	....
Engineering	....
Contingencies (...% of (a))	....
TOTAL PROJECT COST (b)	....
COST PER kW ((b)/Plant Capacity(kW))	....

3.7.2 Annual Costs

Annual costs include loan repayments and maintenance and repair costs; these were discussed in Chapter 1, Section 1.8.2. Further discussion of maintenance and repair costs are given below.

Maintenance

Allow costs for the following maintenance and repairs:

- Intake
  - Cleaning of trashracks by hand - weekly
  - Cleaning of sand out of headpond or settling tank - monthly
  - Major cleanouts of sand, gravel and tree debris after exceptionally heavy rain or snowmelt - two per year
- Penstock
  - Prevention of washouts along steep hillsides
  - Prevention of trees falling onto pipe
- Powerhouse
  - Maintenance of building
- Machinery
  - Daily inspection (by owner)
  - Annual shut-down, inspection, maintenance and repair (by turbine manufacturer)

Most of this maintenance will be done by the owner so the cost will depend on how you want to charge your time. You will probably need a small cat or backhoe for the major cleanout of the intake: allow five days per year.

The annual inspection and maintenance of the turbine and generator will be done under a contract with a turbine manufacturer: allow $2000 per year.

For the total annual maintenance and repair costs allow 2 percent of the Total Project Cost calculated in Section 3.7.1.

Recalculate the annual loan repayments using the method described in Chapter 1, Section 1.8.2, with the new Total Project Cost from the Summary of Project Costs table in Section 3.7.1 above.

3.8 PRELIMINARY ASSESSMENT OF FEASIBILITY

To help you assess the feasibility of your planned project, consider the following:

1. Will there be enough power and energy generated from your hydro plant (and supplementary diesel, if necessary) to meet your loads at all times of the year?

2. Do you foresee any problems in borrowing money to build your hydro plant? Will borrowing for the hydro plant affect other financial arrangements you have?

3. Is the average cost of energy from your proposed hydro plant (or from hydro and diesel) less than the cost of energy from an alternative source, such as:

(a) A diesel plant only, or
    (b) A transmission line extension from an existing B.C. Hydro transmission line?

4. Is it really practical to build the project you have selected?

If you went through the plant sizing procedures in Sections 3.5.2, 3.5.3 or 3.5.4 you will have a good background from which to answer these questions. If all your answers are "yes", the project can be considered feasible, and you can continue planning.

If you are not sure about any of these questions, or any others not listed, you can still continue planning. But your first priority would be to do whatever is necessary to confirm that the project is feasible and that you want to build it.

The next stage in the planning process will involve other people in your project, and might incur expenses.

3.9 CONTINUED PLANNING

Next, consider the following:

(a) hiring an engineer or a building contractor,
(b) borrowing money,
(c) permits, licences and legal aspects, and
(d) turbine manufacturers.

Hiring an Engineer or Contractor

If you will be hiring an engineer to do part or all of the remaining planning and design work, now is the time to discuss your project with him or her. An engineer could advise or assist you in Items (b), (c), and (d) above. Review the discussion in Chapter 1, Section 1.7 on seeking professional advice.

If you plan to hire a contractor to do a major part of the construction, consider getting professional advice on preparing contracts and specifications.

Borrowing Money

If you need to borrow money or intend to seek grants or other financial assistance from Federal or Provincial government agencies, you should start making enquiries. You will probably have to prepare detailed information to back up your requests. Your chances of getting financial assistance will improve with the quality and quantity of relevant information you present.

Find out as soon as possible what information each bank, institution or agency requires. Then prepare the information for your requests or discussions.

Permits, Licences and Legal Aspects

These are discussed in Chapter 5. Now is the time to find out what has to be done.

Turbine Manufacturers

Turbine manufacturers can help you plan your hydro project. Before they can give you any advice or prices for their equipment, they will need information about the site. Use the Information Request form in Supplement 3.3 at the end of the chapter to send to several turbine manufacturers.

A list of turbine manufacturers is given in Appendix C.

TABLE 3.2

LOAD INVENTORY FORM

1	2	3	4	5	6	7	8
				Load Contribution			
				Summer		Winter	
Description	Rating kW	Daily Use Summer/ Winter Hours	Category	Peak (kW)	24 Hour (kW)	Peak (kW)	24 Hour (kW)
TOTALS (kW)							
TOTALS WITHOUT SPACE HEATING							
TOTALS WITHOUT FULLY INTERRUPTABLE LOADS							

TABLE 3.3

TYPICAL HOUSEHOLD APPLIANCE LOADS

Appliance	Average wattage	Average kw/h used per year
Dishwasher (does not include hot water)	1200	216
Fan	75	96
Kitchen Waste Disposer	375	24
Microwave Oven	1400	240
Range	12000	780
Range - Self-Cleaning (includes cleaning)	12000	828
Dryer	4600	960
Iron	1000	48
Washer - Automatic (does not include hot water)	500	96
Freezer - Chest	340	1080
Freezer - Upright	340	1260
Freezer - Upright Frost-Free	375	2100
Refrigerator - Manual Defrost	400	720
Refrigerator-Freezer - Automatic Defrost	800	1440
Refrigerator-Freezer - Frost-Free	900	1800
Hi-Fi or Stereo	150	132
Radio	50	48
Television - Colour	200	360
Television - Black and White	100	180
Water Heater - 30 Gallon	2000/1000	5760
Water Heater - 40 Gallon	3000/3000	6480
Blanket - Double	180	120
Heater - Auxiliary	1000	600
Sun Lamp	400	48
Waterbed	400	1200
Hair Setter	600	24
Hair Dryer	1100	108
Coffee Percolator	600	72
Fry Pan	1150	72
Kettle	1500	264
Mixer	150	12
Toaster Oven	1400	240
Toaster	1000	36
Block Heater	500	1152
Car Warmer	800	1620
Lawnmower	1000	120

TABLE 3.3 (Continued)

TYPICAL HOUSEHOLD APPLIANCE LOADS

Appliance	Average wattage	Average kw/h used per year
Clock	4	35
Furnace Blower	250	600
Lamp, 100 Watt	100	108
Sewing Machine	100	12
Vacuum Cleaner	500	36
Shop Equipment:		
Water pump (1/2 hp)	460	240
Shop drill (1/2", 1/2 hp)	250	10
Skill saw (1 hp)	1000	80
Table saw (1 hp)	1000	80
Lathe (1/2 hp)	460	10
Space Heating	See Table 3.6	

Note:

This is a guide only.

Average energy consumption per year is based on a family of four using an average amount of electricity. Consumption for a particular household could differ considerably from these figures because of different hours of use and different wattages of appliances.

TABLE 3.4

DAILY LOAD LOG FORM

APPLIANCE OR EQUIPMENT	WATTS	HOURLY LOAD SCHEDULE																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
TOTAL HOURLY LOAD IN kW (Watts/1000)																									

TABLE 3.5

EXAMPLE OF DAILY LOAD LOG

APPLIANCE OR EQUIPMENT	WATTS	HOURLY LOAD SCHEDULE																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
General:																									
Lights	1200						.3	.6	.6									.3	.6	1.	1.	1.	.5	.8	
Space Heating	10000	1.	1.	1.	1.	1.	6.	6.	6.									6.	6.	6.	6.	6.	6.		
Hot Water	4000						—	—	—										—						
Washer	600								—																
Drier	2500									—															
Radio/Stereo	100							—	—	—	—				—	—									
T.V.	300																								
V. Cleaner	800										—														
Kitchen:																									
Fridge	500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Deep Freeze	400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Micro. Oven	1200																	—	—						
Toaster	1200						—	—																	
Blender	600																		—						
Workshop:																									
Table Saw	1000																—	—	—						
Skill Saw	1000																								
TOTAL HOURLY LOAD IN kW (Watts/1000)		1.9	1.9	1.9	1.9	1.9	12.4	12.8	12.2	3.6	1.8	0.9	0.9	0.9	1.0	1.3	2.2	9.7	13.0	8.2	8.2	8.2	11.4	1.2	0.9

TABLE 3.6

TYPICAL ANNUAL ELECTRICITY CONSUMPTION AND MAXIMUM LOADS FOR SINGLE FAMILY RESIDENCE

	Annual Consumption kW.h/m^2 (1)	Maximum Load kW
1. Lighting and Appliances only: (non-electric water or space heating)	77	6
2. Lighting, Appliances and Electric Water Heating (non-electric space heating)	110	10
3. Electric Space Heating only: (add to Items 1 or 2 above as applicable)	kW.h/m^2/1000 DD (2)	kW/m^2 (1)
a) House built before 1960 (3)	31	0.21
b) House built to 1975 standards (4)	24	0.16
c) House built to Double E standards (5)	12	0.082
d) House built to Super Double E standards (6)	8	0.05

Notes:

1. To find maximum load (kW) and annual consumption (kW.h) multiply values in table by floor area in square metres.
2. To find annual heating consumption (kW.h) multiply values in table by floor area in square metres and degree-days (°C) for place nearest to your residence: degree-days are given in table below.
3. Insulation: R7 ceiling, R7 above grade walls, single glazed windows.
4. Insulation: R20 ceiling, R12 above grade walls, single glazed windows.
5. Insulation: R40 ceiling, R20 above grade walls, R12 below grade walls, double glazed windows.
6. Insulation: same as in Note 5. House must also comply with other energy conservation requirements specified by Canadian Electric Association (information from B.C. Hydro).

DEGREE-DAYS (CELCIUS) FOR VARIOUS PLACES IN B.C.

Abbotsford	3100	Fort St.John	6100	Port Hardy	3700
Alberni	3200	Golden	4900	Prince George	5400
Atlin	6700	Grand Forks	4000	Prince Rupert	3900
Bella Coola	3800	Hope	3100	Quesnel	4900
Burns Lake	5800	Kamloops	3700	Revelstoke	4200
Campbell River	3400	Kaslo	4000	Smithers	5400
Castlegar	3700	Kelowna	3600	Stewart	4600
Cranbrook	4800	Kimberley	4900	Telegraph Creek	5800
Dawson Creek	6200	Kitimat	4100	Terrace	4300
Dease Lake	7000	Masset	3800	Vancouver	2900
Fernie	4800	Merritt	4300	Vanderhoof	5700
Fort Nelson	7100	Nanaimo	3100	Victoria	3200
Fort St.James	5700	Nelson	3700	Williams Lake	5100

TABLE 3.7

COINCIDENCE FACTORS FOR PEAK LOADS OF GROUPS OF RESIDENCES

Number of Residences Connected to Hydro Plant:	2	3	4	5	6	7	8	10	12	15
Coincidence Factor For Peak Load:	0.77	0.67	0.62	0.57	0.54	0.51	0.49	0.47	0.45	0.42

Total load (kW) on the hydro plant equals sum of all individual peak loads multiplied by Coincidence Factors for number of residences.

See text Section 3.2.2 for an example.

COINCIDENCE FACTORS FOR HEATING ENERGY FOR MULTIPLE UNITS

Number of Attached Living Units:	2	3	4	5 or more
Coincidence Factors for Electric Space Heating:	0.7	0.65	0.60	0.55

Total annual electric space heating consumption (kW.h) for a building with several living units equals the sum of the consumption for all units multiplied by the Coincidence Factor for the number of units.

TABLE 3.8

TYPICAL ELECTRIC LOADS IN MOTELS (1)

	Average	High
1. Maximum Demand (2): $kW.h/m^2$	0.06	0.16
2. Annual Consumption (3): $kW.h/m^2/1000$ DD	50	160

Proportions of Total Electric Consumption:

i) Lighting and other applicances	up to 30%
ii) Space heating and water heating	60 - 70%

Notes:

1. Data taken from seven motels on Vancouver Island, for 1981. The values apply to motels operating year-round. Consumption for motels closed for part of the year would be less than the average values shown.

2. Maximum load in kW per square metre of floor area.

3. Annual consumption per square metre of floor area per thousand degree-days (Celcius) of outside temperature below 18°C. Average annual degree-days can be obtained from Table 3.6.

4. Example calculation given in text, Section 3.2.3.

TYPICAL CAMP LOADS

	Average (2) kW/Person	High (3) kW/Person
Maximum load for camp with combined electric baseboard and propane space heating: (1)	1.0	1.5
Maximum load for camp with all-electric space heating: (1)	1.5	2.0

Notes:

1. Propane used for cooking.

2. Use average values for well insulated units.

3. Use high values for poorly insulated units or cold climates, e.g. Northern B.C.

TABLE 3.9

PROCEDURE FOR SIZING YOUR HYDRO PLANT FOR A KNOWN LOAD

See Section 3.5.2 for a discussion on steps in this table.

Step No.

Estimating Loads:

1.* Calculate maximum daily load - specify time of year.
2.* Calculate maximum daily load for the 3 months with the lowest monthly flows - specify times of year.
3.* Calculate monthly variation of peak load throughout the year.

Estimating Streamflows:

4.* Estimate minimum expected flow Qmin - specify time of year.
5. Calculate average flow.
6. Draw flow-duration curve.

Sizing Plant: Trial 1 - Use Minimum Flow:

7.* Select plant capacity (P_1) kW:
P_1 = Maximum daily load without fully interruptable loads plus 10 percent
8.* Compute gross head required (Hg) using Qmin:

$$Hg = \frac{P_1}{Qmin \times 5.9}$$

9.* Examine site - can you build a project with a head equal to H?

If "YES" go to step 10
If "NO" go to step 16

10.* Make preliminary layout of project (see Section 3.6).
11.* Estimate capital cost of project (see Section 3.7).
12.* Compute average annual hydro energy available (kW.h).
13.* Compute cost of hydro energy in ¢/kW.h.
14. Either: Go to Step 34 (Trial 2) to compare other project layouts;
15.* Or: Use layout from Trial 1 and go to Section 3.8 to make preliminary assessment of feasibility.

* * * *

16. If "NO" to step 9 there is not enough power available with the flow Q_{min}; there are 3 options (a), (b)(Step 17), or (c)(Step 27).
a) Go to Step 34 (Trial 2)
17. Or b) Consider using diesel as supplementary power source:
18.* Select a head (H_2) that is suitable for the site.
19.* Compute power available (P_2) using flow available 95 percent of the time (Q_{95} from flow-duration curve)

$$P_2 = Q_{95} \times H_2 \times 5.9$$

TABLE 3.9 (Continued)

Step No.

20.* Compute average annual energy available from hydro using Q_{95} as upper limit.
21.* Estimate average annual energy required (from load inventory).
22.* Compute supplementary annual energy required from diesel (values from Steps 21 minus 20).
23.* Compute cost of diesel-generated electricity (¢/kW.h).
24.* Do Steps 10 to 13 to get cost of hydro energy (¢/kW.h).
25.* Compute total cost of energy from hydro and diesel.
26. Go to Section 3.8 to make preliminary assessment of feasibility.

* * * *

27. Or c) Consider building a storage dam to supplement flows:
    If there is a suitable site for a storage dam and reservoir,
28. Compute the size of reservoir (using mass-curve Appendix J) and height of dam.
29. Compute additional cost of storage dam.
30. Estimate average annual energy from storage.
31. Compute cost of energy from storage (¢/kW.h).
32. Compare energy costs of storage and diesel.
33. Go to Section 3.8 and make preliminary assessment of feasibility.

* * * *

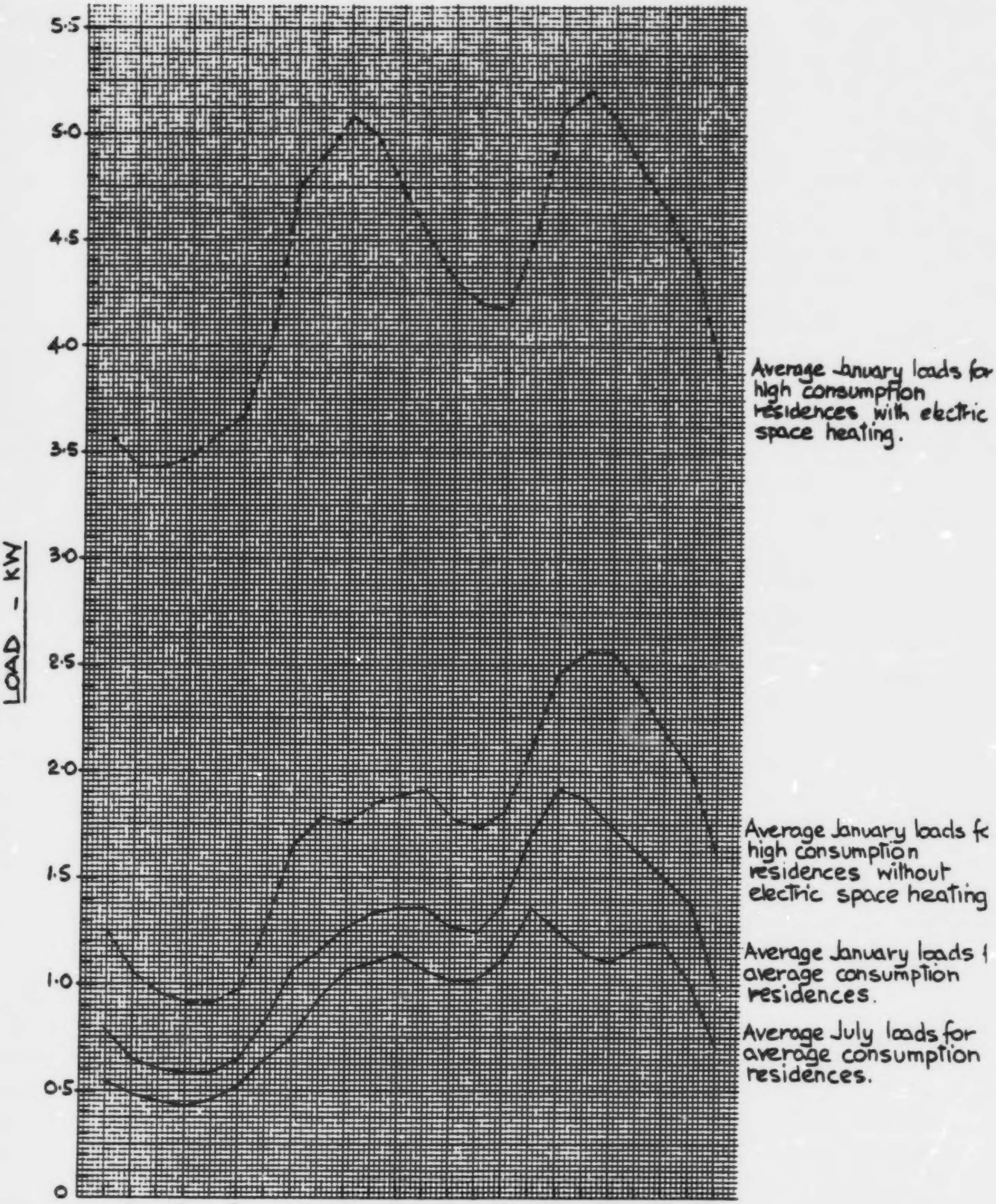
Sizing Plant: Trial 2 - Use 75 Percent Exceedance Flow:

34. Do Steps 7 and 8 using 75 percent exceedance flow from flow-duration curve - use same plant capacity P_1, and compute new head H_3 (less than H_1).
35. Examine site - is site suitable for project with Head H_3
36. If "YES":
    Do Steps 10 to 13, modifying layout and calculations from Trial 1 (see Section 3.6).
37. Compare cost of hydro energy in (¢/kW.h) from Trials 1 and 2.
38. If Trial 1 cost (¢/kW.h) is less than Trial 2 cost (¢/kW.h), use Trial 1 layout and go to Section 3.8.
39. If Trial 2 cost (¢/kW.h) is less than Trail 1 cost (¢/kW.h), repeat Trial 2 using 60 percent exceedance flow.
40. Select, from Trial 2 or 3, layout which represents least cost of energy (¢/kW.h), and go to Section 3.8.

* * * *

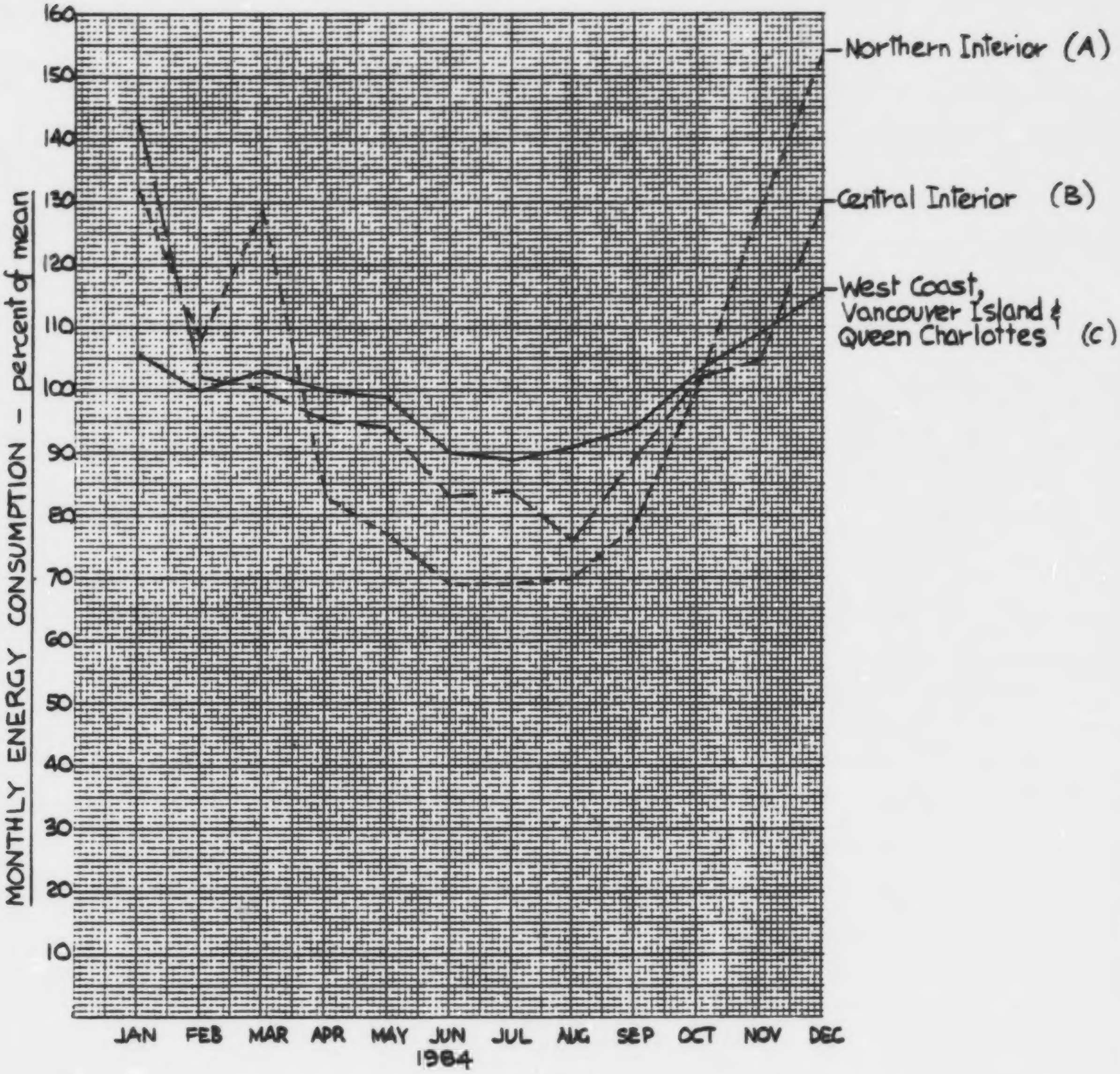
41. If "No" to Step 35:
    Consider using diesel as supplementary power source.
42. Do Steps 17 to 26.

* Step Nos. marked with asterisk are for Simplified Procedure - see Section 3.5.3 for discussion.



Source : B.C. Hydro.
Average consumption is 1280-2050 kW.h/year : High consumption is over 2050 kW.h/yec

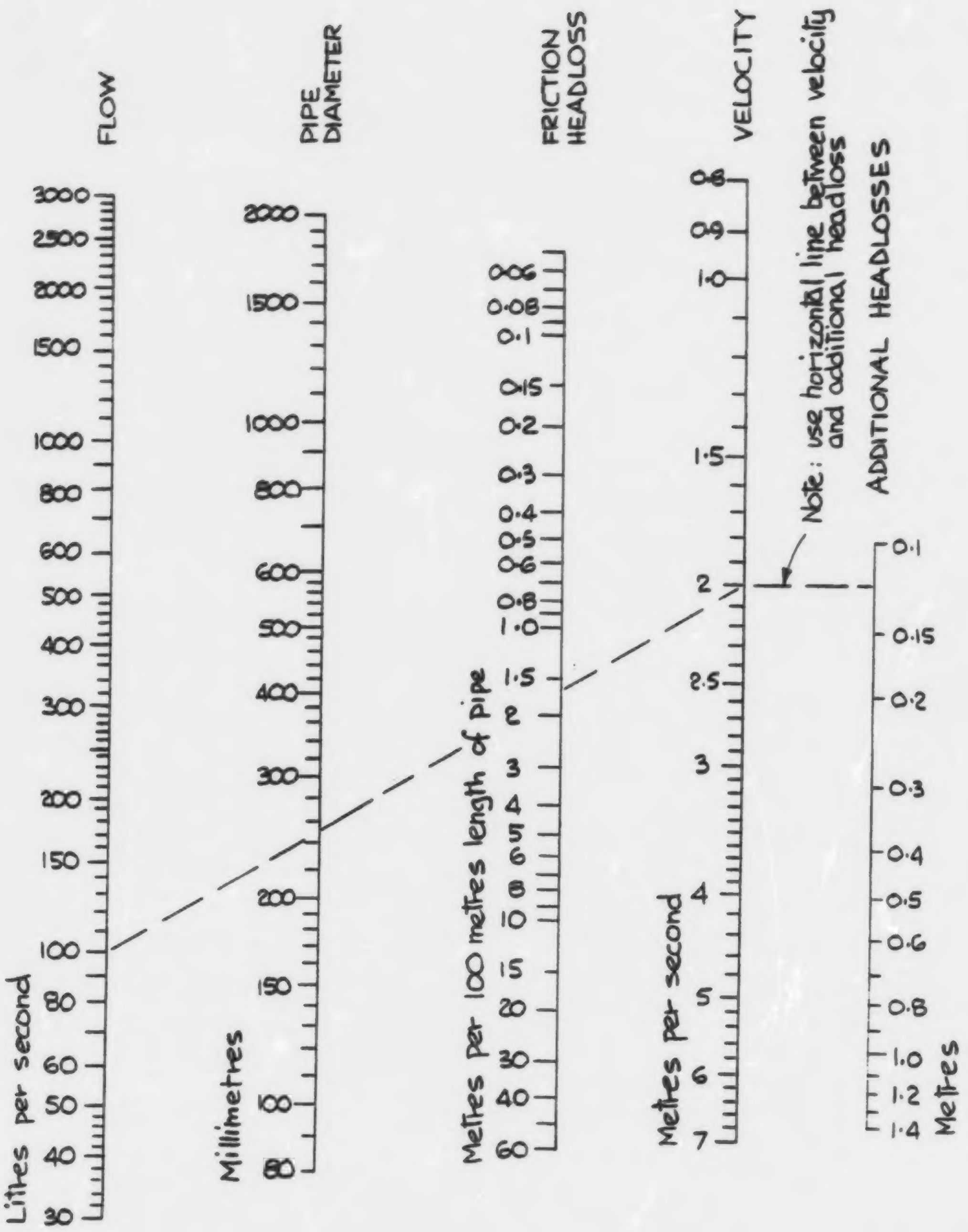
FIG 3.1 : AVERAGE. DAILY LOAD CURVES



The graphs show energy consumption in the following remote communities:

Northern Interior ...... Dease Lake
Central Interior ...... Anahim Lake
West Coast,
Vancouver Island,
Queen Charlottes ...... Masset

FIG 3·2 MONTHLY ENERGY CONSUMPTION VARIATIONS (BC COMMUNITIES)



Note: For steel pipe multiply headlosses from this nomograph by 1·23

Example: Flow = 100 L/s ; Velocity = 2 m/s
From nomograph: Pipe dia. = 250 mm ; Headloss = 1·7 m/100m
Additional headloss = 0·12 m

FIG 3·3 HEADLOSS NOMOGRAPH FOR PLASTIC PIPE

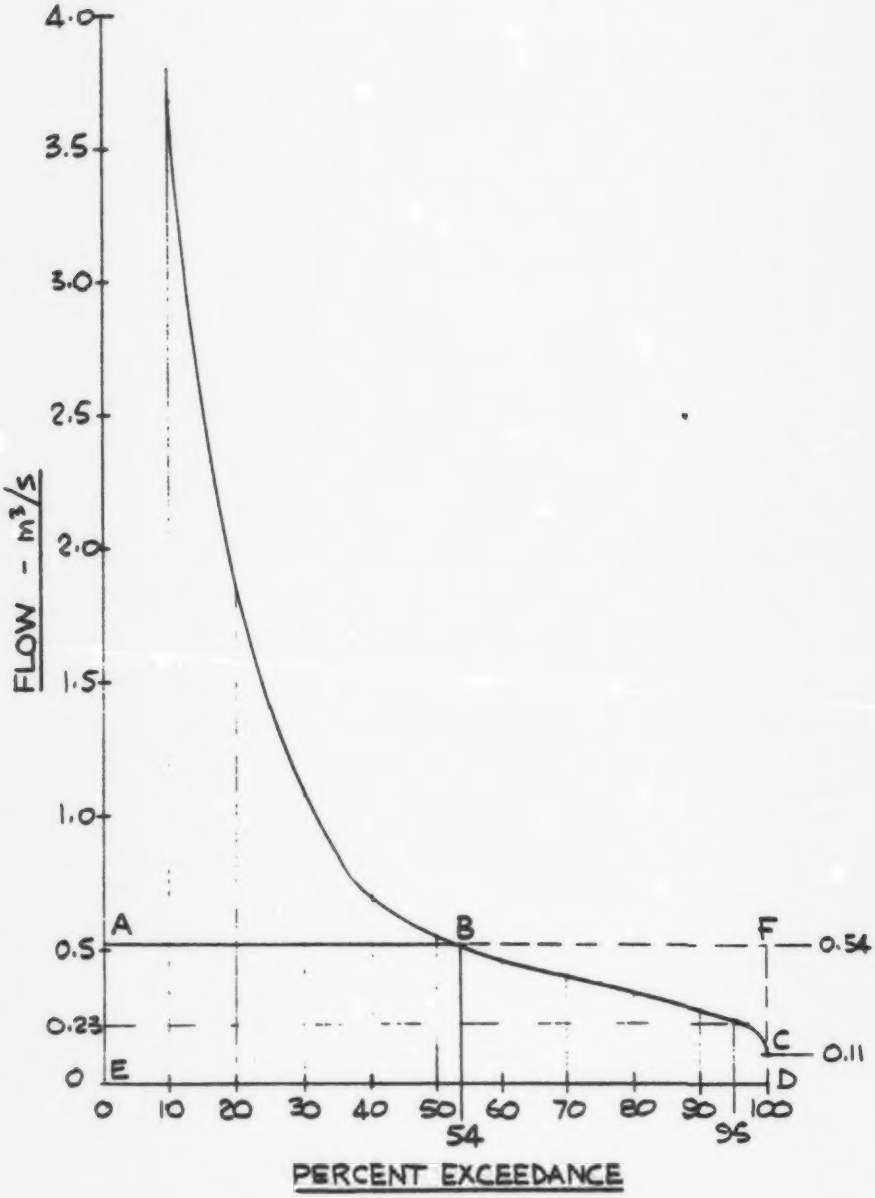
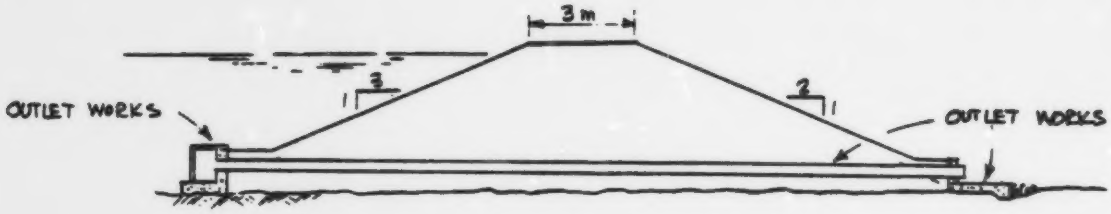
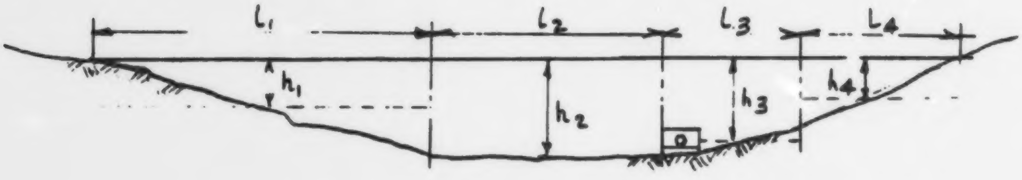


FIG 3.4 ANNUAL FLOW-DURATION CURVE

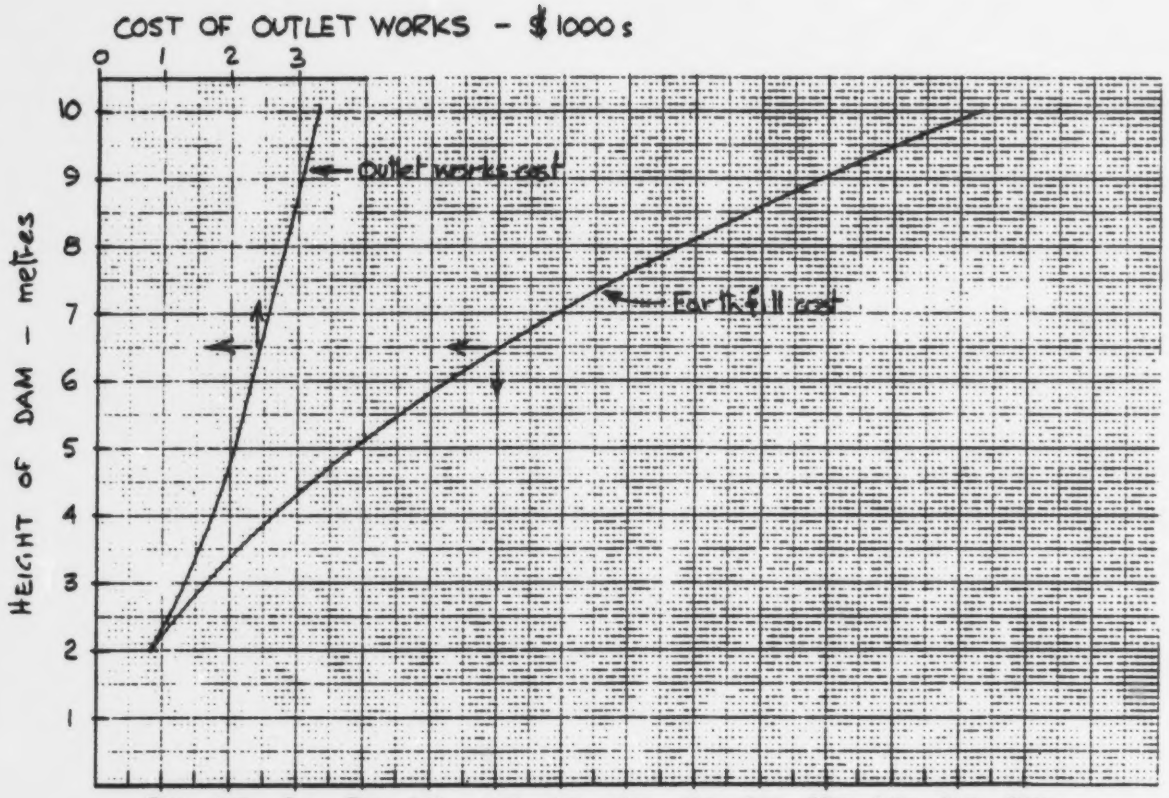
Note: See text section 3.4.3 for an example of the use of this curve.


3m
3
1
2
1
OUTLET WORKS
OUTLET WORKS

TYPICAL CROSS-SECTION

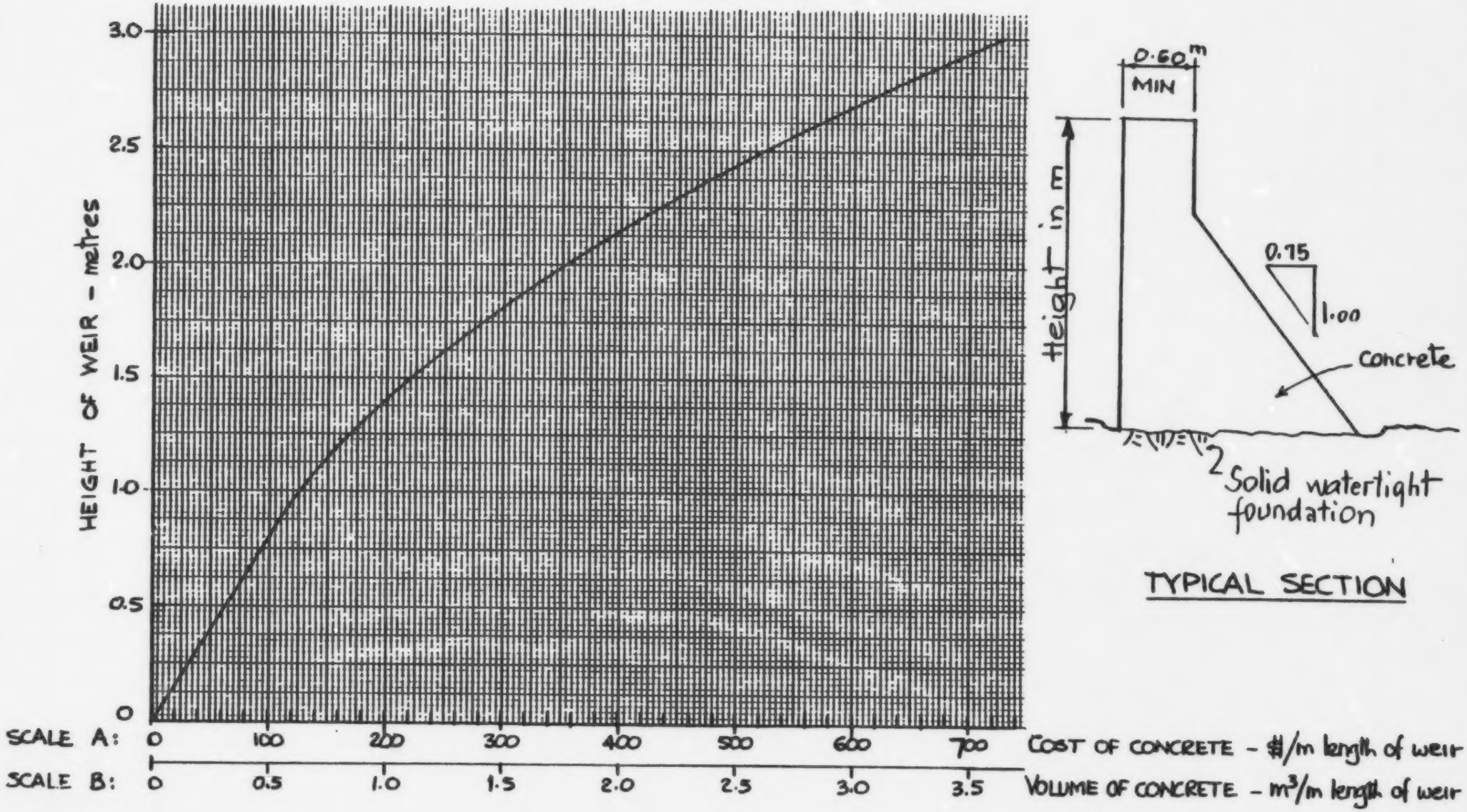

L1
L2
L3
L4
h1
h2
h3
h4
o

LONGITUDINAL SECTION ALONG CENTRELINE



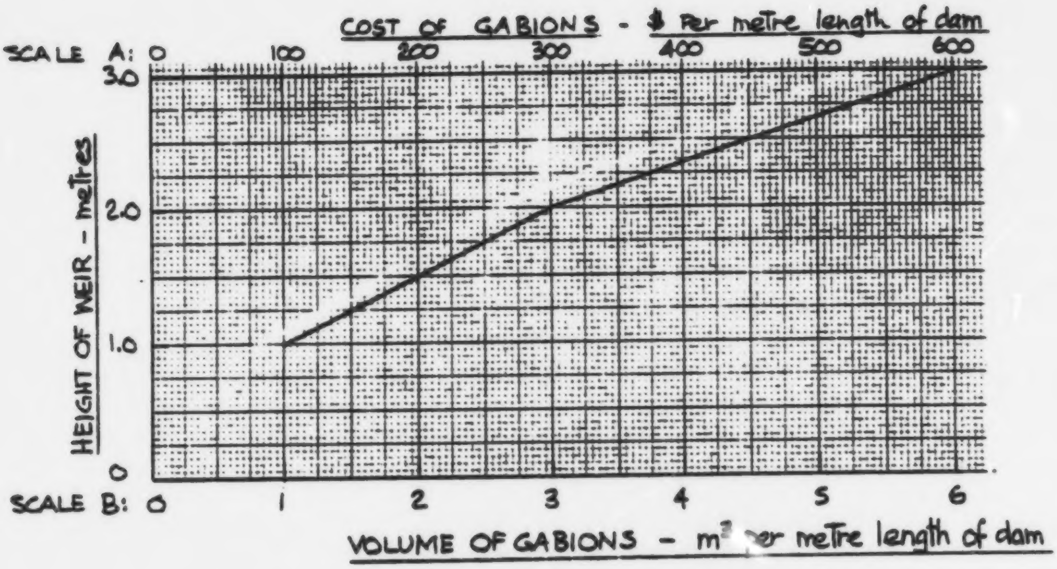
Read Section 3.7.1 "Storage Dam" to find out how to use this curve.

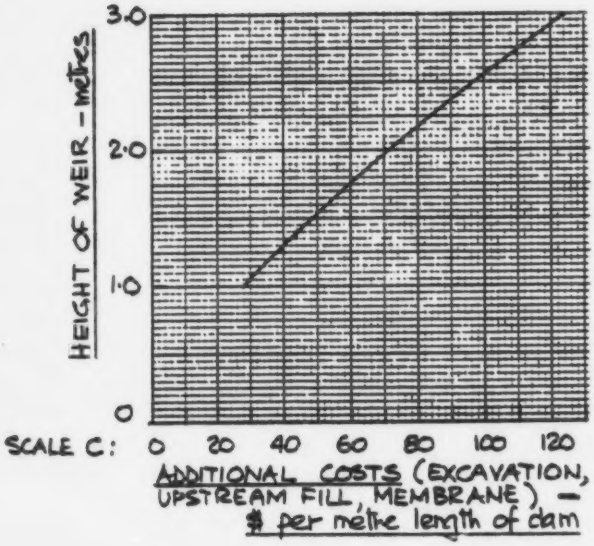
FIG 3·5 EARTHFILL DAM COST

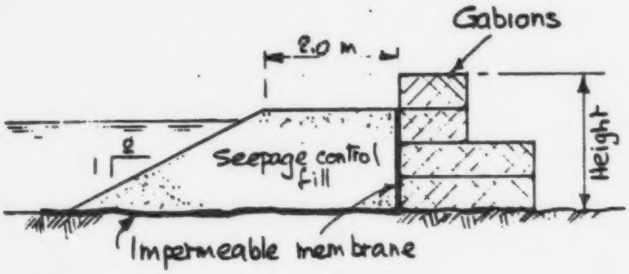


Note: Read Section 3.7.1 "Intake Weir" in the text to find out how to use this curve

FIG 3.6 CONCRETE WEIR VOLUME AND COST



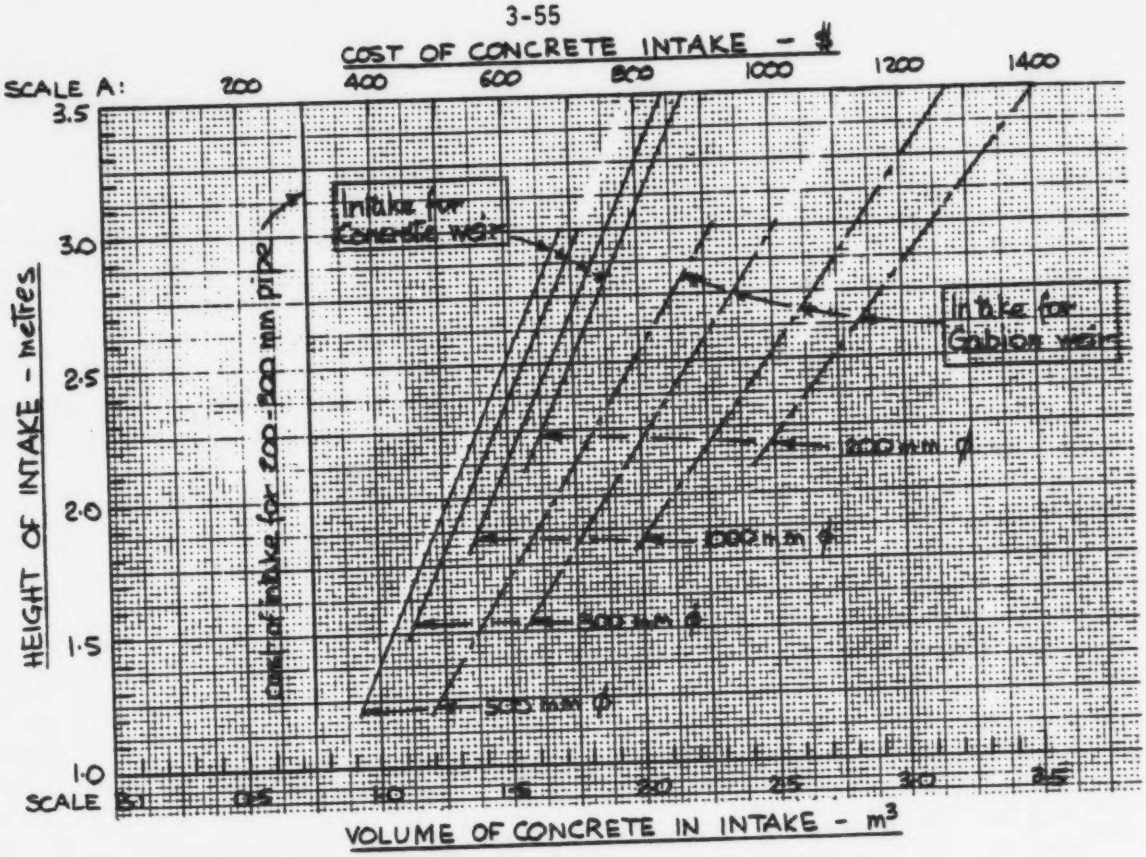


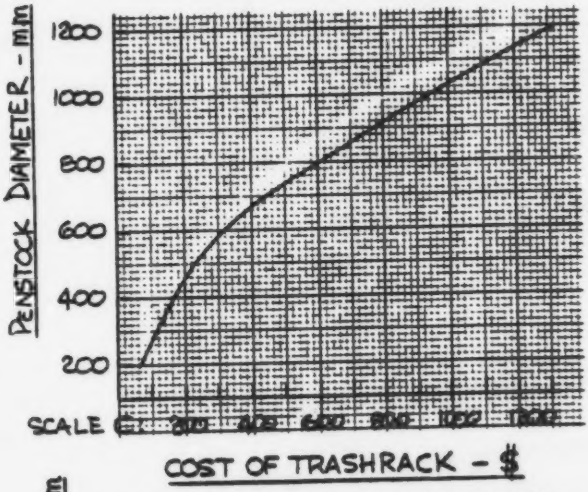

Gabions
2.0 m
Height
1
2
Seepage control fill
Impermeable membrane

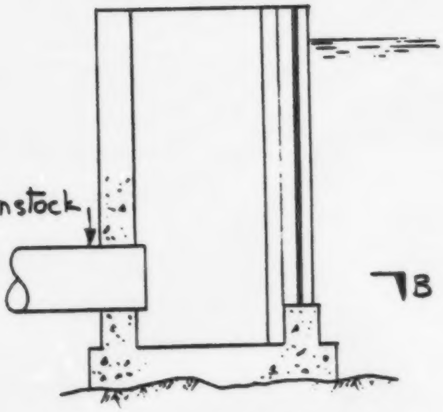
TYPICAL CROSS-SECTION

Note: Read Section 3.7.1 "Intake Weir" in the text to find out how to use these curves.

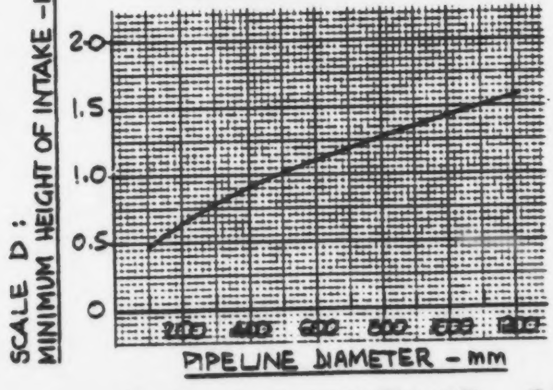
FIG 3.7 GABION WEIR COST

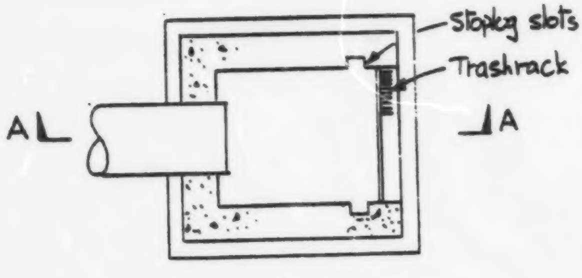





Penstock
B
B

SECTION A-A

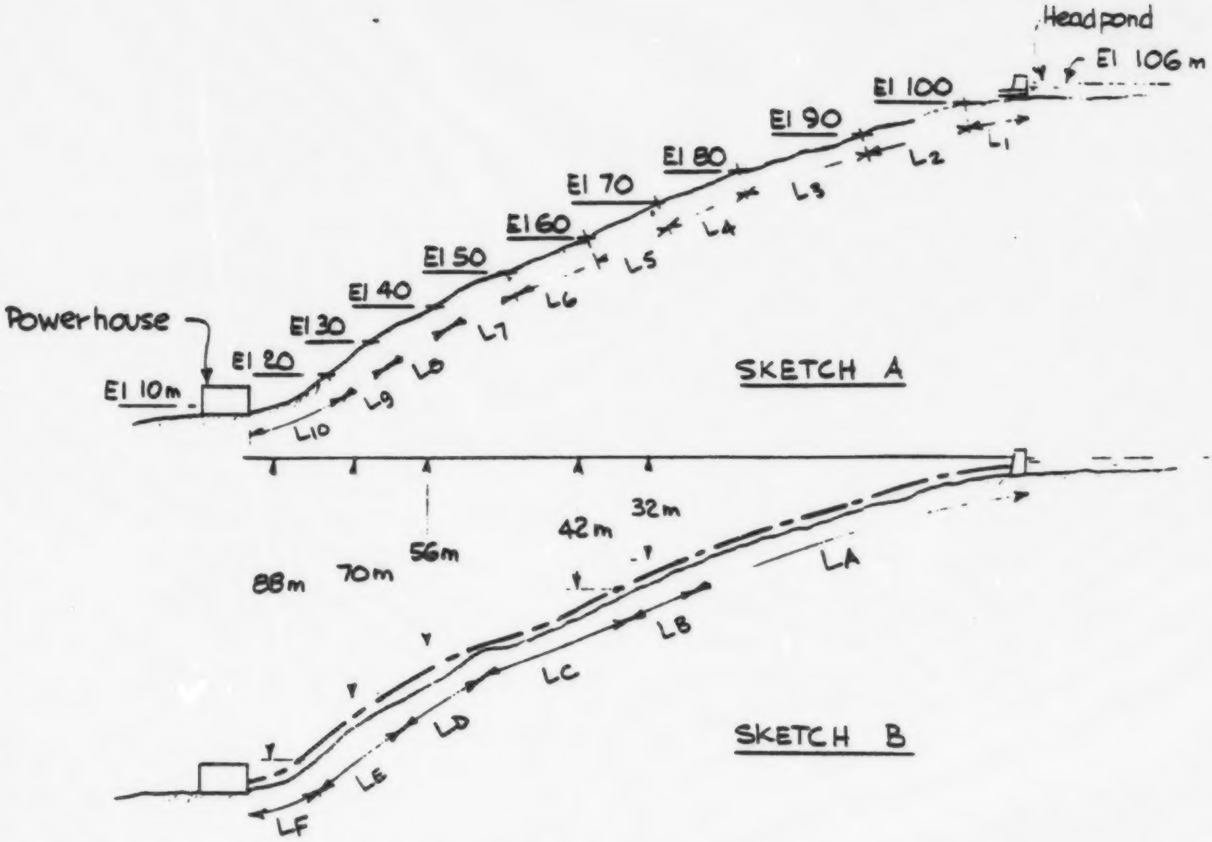



Stoplog slots
Trashrack
A
A

SECTION B-B
INTAKE FOR GABION WEIR

Note: Read Section 3.7.1 "Pipeline Intake" to find out how to use these curves.

FIG 3.8 INTAKE COST


Headpond
El 106 m
El 100
El 90
El 80
El 70
El 60
El 50
El 40
El 30
El 20
El 10m
Powerhouse
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
SKETCH A
88m
70m
56m
42m
32m
LA
LB
LC
LD
LE
LF
SKETCH B

PIPE CLASS	GROSS HEAD - m	NOMINAL PIPE DIAMETER - mm (1)					
		200	315	500	800	1000	1200
	FROM - TO	COST OF PIPE PER METRE - $/m					
A	0 - 31·6	25	64	155	405	625	910 (2)
B	31·6 - 42·2	35	80	205	530	1030	1235
C	42·2 - 56·2	43	106	265	683	1030	1235
D	56·2 - 70·3	52	128	324	830	1030	1235
E	70·3 - 87·8	62	154	518	830	1030	1235
F	87·8 - 112·5	78	190	518	830	1030	1235
G	112·5 - 140·6	92	220	518	830	1030	1235
H	140·6 - 150·0	170	330	518	830	1030	1235
COST OF VALVE - $		240	410	2,630	7,740	10,400	17,700

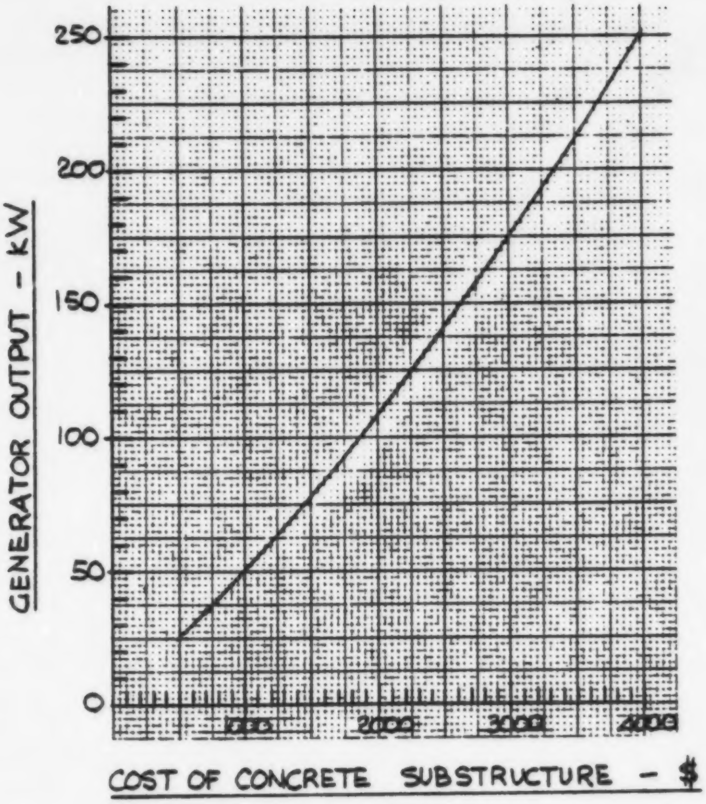
Notes

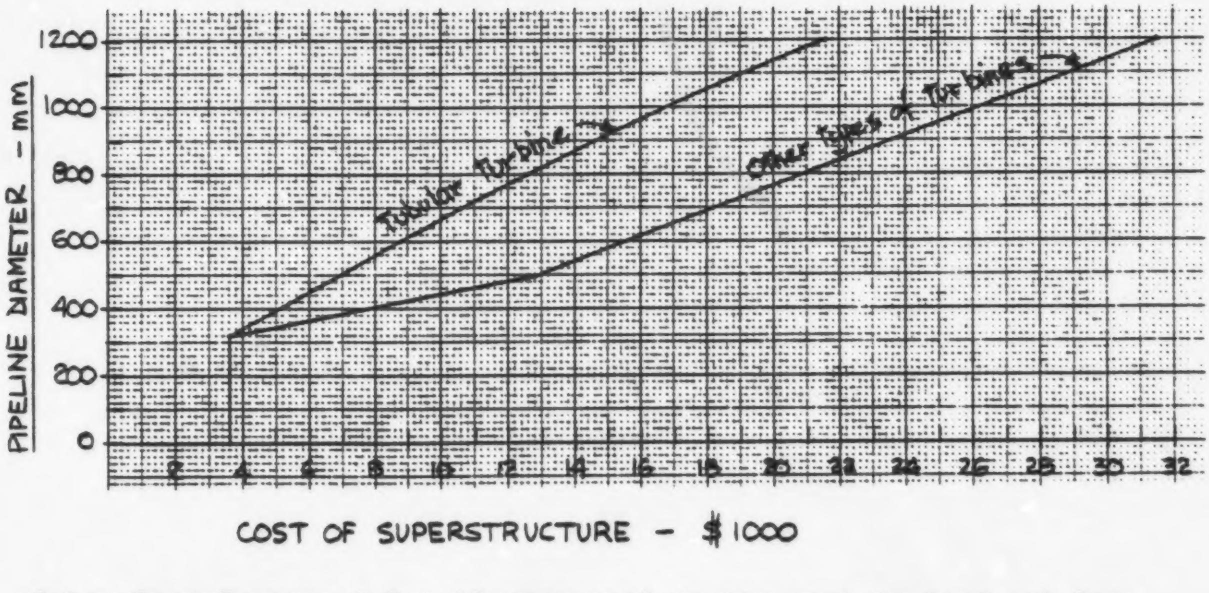
1. Nominal outside diameter of pipe. The inside diameter will be less and will depend on the gross head.

2. Costs above the heavy line are for polyethylene pipe: costs below the line are for steel pipe.

3. Read Section 3.7.1 "Pipeline" in the text to find out how to use this table.

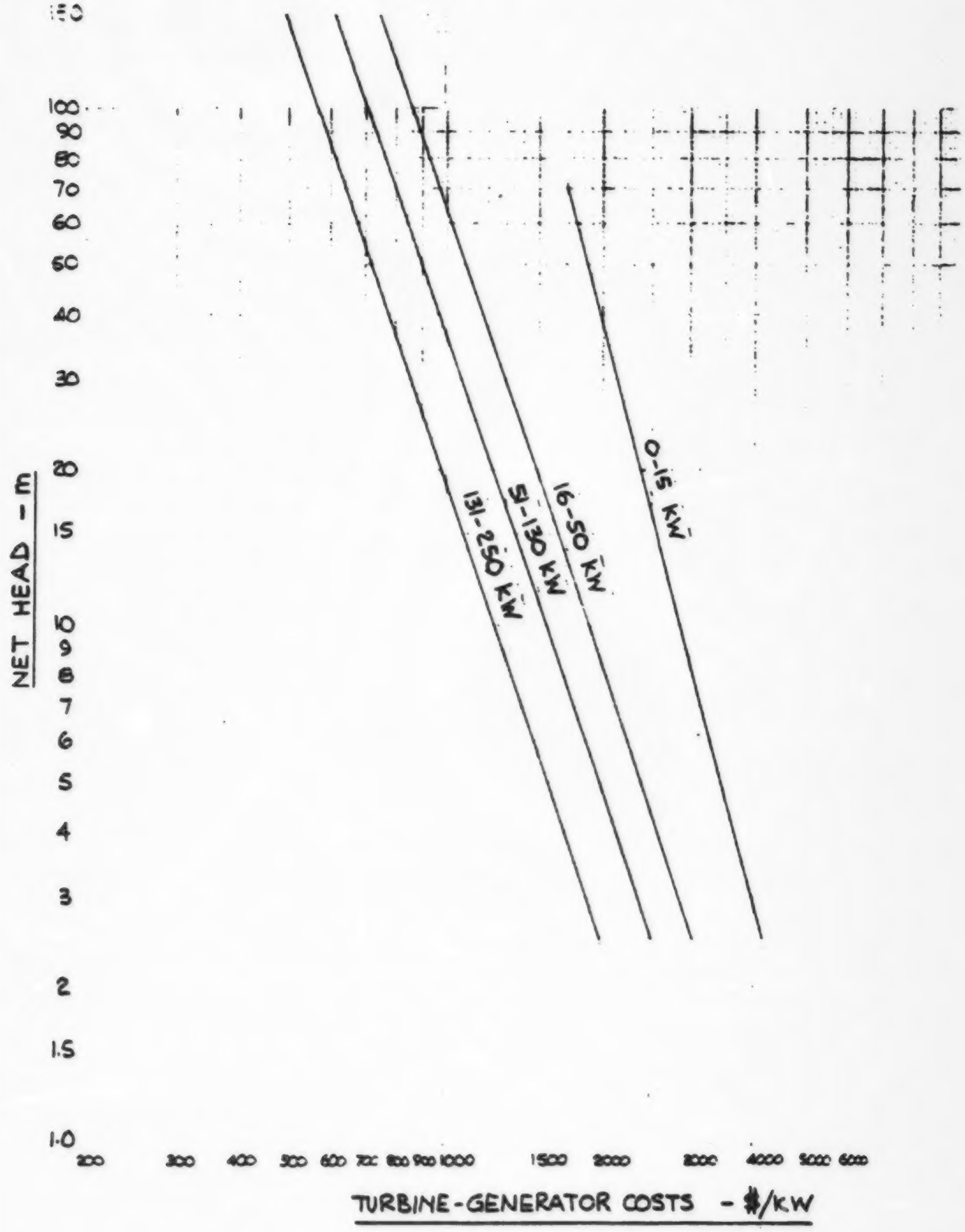
FIG 3·9 PIPELINE COSTS FOR POLYETHYLENE PIPE





Note: Read Section 3.7.1 "Powerhouse" in the text to find out how to use these curves.

FIG 3.10 POWERHOUSE COST



Note: Read Section 3.7.1 "Turbine-Generator-Electrical Equipment" in the text to find out how to use this graph.

FIG 3·11 TURBINE-GENERATOR COSTS

SUPPLEMENT 3.1

FLOW DURATION CURVES

1.0 PLOTTING A FLOW-DURATION CURVE

Figure A shows a typical flow-duration curve: the solid line is flows in the Quinsam River on Vancouver Island, 1956-82. The processing of streamflow data for plotting such a curve is simple but lengthy when done by hand: it takes several hours to process 20 years of daily data. Using monthly data is quicker, but the resulting flow-duration curve overestimates the flow available for power.

There probably will not be a Water Survey of Canada (WSC) gauge on the stream you want to develop for hydropower. You will probably have to select a nearby gauged stream, construct a flow-duration curve for the gauged stream, then covert this curve to make it apply to your project stream. The procedure is explained below.

1.1 Streamflow Data for a Flow-Duration Curve

Ask the nearest Water Management Branch office for:

(a) flow-duration data for streams near your stream, or

(b) the name of a gauged stream whose data would be suitable to construct a flow-duration curve for your stream - we shall call this the Project Stream.

If flow-duration data is not available, you must select a gauged stream which has flow characteristics similar to the Project Stream. Obtain from Water Survey of Canada a map entitled, British Columbia Active Hydrometric Stations. When selecting a comparable stream, consider the following characteristics of the gauged stream and the Project Stream:

(a) similar size of drainage basin - you will probably want the smallest gauged basin that exists nearby,
(b) same side of mountain ranges,
(c) same exposure to major weather systems,
(d) close location, if possible, within 50 km,
(e) similar elevation of basin, especially in the headwaters where snow falls,
(f) similar area of lakes and marshes (if any).

The gauged stream should also have at least 10 years of record.

Having selected a gauged stream, obtain from Water Survey of Canada, copies of the Daily Discharges for each year of record, and the Monthly Mean Discharges for the gauged stream. Examples are shown in Table A.

1.2 Procedure for Processing Streamflow Data

All the daily streamflow data has to be grouped into 15 - 20 classes, each defined by an upper and a lower limit. The total number of flows in each class will then become a point for plotting the flow-duration curve.

From the lowest two tables in Table A, which show the "Monthly and Annual Discharges" and "Annual Extremes of Discharge" read off the following values:

	Example	Your Value
Minimum Daily Flow (m^3/s)	0.889	....
Mean Flow (m^3/s)	8.78	....
Maximum Daily Flow (m^3/s)	218.	....

These will help you decide on the class limits or points to be plotted. Referring to Figure A, you need about 10 classes (points) to define the curve below the mean flow. The class sizes need not be the same throughout the total range of flow from minimum to maximum. The class limits selected for the Quinsam River are shown in Table B(A), in the left column.

Table B(A) illustrates the procedure for processing one year of data (1983). Using the "Daily Discharges" for 1983 (from Table A), start with January 1, count the flows within each class, and write them into the "No. of Occurrences" column, for example:

	Flow m^3/s	No. of Occurrences
January 1-2	7-10	2
3-5	10-15	3
6-7	7-10	2
8-9	10-15	2
10	15-20	1
11-15	20-40	5

Do this for the whole year. Add the flows in each class, enter them in the right column, then add all the totals in this column to check that they all add up to the number of days in the year (365 or 366 for a leap year). Don't worry if you are one or two days out.

Repeat this procedure using a separate sheet of at least 10 years. If there are more than 10 years of record, select 10 consecutive years that include the years with the lowest flows according to the Monthly and Annual Mean Discharges.

Then, on a separate piece of paper, tabulate all the "Total Columns" for each year (Example: Table B(B) Columns #2 to #6). Add these annual totals to get the totals for each class for all years (Column #7). Add the values in Column #7 to get the grand total (1826), which should be the total number of days in all the years you've used.

Starting from the bottom of Column #7, accumulate the values and write them in Column #8. Then divide each value in Column #8 by the grand total (1826) and multiply by 100 to get percentages of the total (Column #9). The values in Column #1 and #9 are used to plot the flow-duration curve.

To plot a flow duration curve for all or more selected months, say December and January (as suggested in Chapter 3, Section 3.4.3), follow the procedure just explained for the annual flow duration curve, using only the daily flows for December and January. In Tables B(A) and B(B) the total number of occurrences of flows in any year will be 62 instead of 365. The total in Table B(B) Column #7 will be 62 times the number of years of record. And when you plot the flow duration curve, as in Figure A, the scale on the horizontal axis will still be from 0 to 100 percent.

2.0 CONSTRUCTING A FLOW-DURATION CURVE FOR AN UNGAUGED STREAM

The two methods of converting a flow-duration curve from a gauged to an ungauged stream are:

1. Using flows measured simultaneously in each basin.
2. Using the ratio of the two drainage basin areas.

If you have already built a measuring weir on your Project Stream, you will have some useful flow data, so use the first method. For each day that you have a flow in the Project Stream, you need the flow in the gauged stream. Ask Water Survey Canada (WSC) for "preliminary streamflows" on the gauged stream - these should be available about two months after they were recorded at the gauge. Write the Project Stream flows and the Gauged Stream flows into a table (see Table of Measured Flows on Figure B).

Plot the pairs of flows measured each day as shown by the crosses on the graph on Figure B. If you have 20 or more points spread over a wide range of flows you can draw a smooth line through the middle of the points so that there is about the same number of points on each side of the line (we will call this a correlation line).

You will probably find that the plotted flow points do not cover the range of flows you need for the flow-duration curve. This is the case on Figure B. To draw the correlation line over the range of flows you need, you will have to use the ratio of the drainage basin areas.

Suppose that you want a flow-duration curve for flows that are available 50 percent of the time or more. Figure A shows that flows up to 5 m/s are available on the Gauged Stream 50 percent of the time. The flow on the Project Stream that is equivalent to 5 m^3/s on the Gauged Stream can be estimated using the ratio of drainage basin areas, as follows:

$$\text{Flow in Project Stream} = \text{Flow in Gauged Stream} \times \frac{\text{area of Project Stream}}{\text{area of Gauged Stream}}$$

Example:

Project Stream Drainage Area 12.5 km^2
Gauged Stream Drainage Area 280.0 km^2
Flow on Project Stream equivalent to 5 m^3/s on the Gauged Stream is: $5 \times \frac{12.5}{280} = 0.22$ m^3/s

On Figure I-2 plot the Point B at 5 m^3/s on the Gauged Stream and 0.22 m^3/s on the Project Stream. Draw a straight line through the other plotted points, through Point B, and extend it to C.

This correlation line can be used to convert the flows in the Gauged Stream to flows in the Project Stream. On the Flow-Duration plot (Figure A) draw a second vertical scale (Scale B) for the Project Stream. For each flow you want to label on the Project Stream scale (Scale B), for example, 0.1, 0.2, 0.3, read from Figure B the equivalent flow on the Gauged Stream: see "Table of Equivalent Flows" on Figure B. These Project Stream flows are plotted on Figure A, Scale B, opposite the equivalent points on the Gauged Stream, Scale A. Using Scale B, the flow-duration curve represents flows on the Project Stream.

3.0 USING FLOW-DURATION CURVE TO SIZE A HYDRO PLANT

When you go through the procedure for sizing your plant (Chapter 3, Section 3.5.2) you will want to know how to use the flow-duration curve to calculate the average energy available from your plant.

First, you should know that the size of the turbine can limit the amount of flow that can be used for energy production.

3.1 Maximum and Minimum Turbine Flows

A turbine can operate within a range of flows from about 105 percent to about 35 percent to 55 percent of the turbine rated flow: the actual range depends on the type and design of the turbine. The rated flow is the flow required to produce the design output of the turbine, with the design head, at maximum efficiency.

For this manual assume that the range of flows the turbine can use is 50 percent to 100 percent of the flow required to produce the design output. When the flow in the stream is less than 50 percent of the turbine rated flow, the turbine cannot operate. Also, any flow in the stream that is greater than the turbine maximum flow will be wasted.

3.2 Energy Output Limited by Turbine Discharges

Figures C(A) and (B) show the flow-duration curve for the Project Stream with two different sizes of turbine.

In Figure C(A) the turbine is sized so that its maximum flow (Line BC) is equal to the flow in the stream that will be available 95 percent of the time (i.e. 95 percent of the time the flow will exceed C or B, and 5 percent of the time the flow will be less than C or B). The minimum flow under which the turbine can operate is $\frac{B}{2} = A$.

As the minimum flow in the stream (D) is always greater than A or E, all the flow in the stream up to a value of B can be used to produce energy.

The area below the turbine maximum flow (BC) and the flow-duration curve (CD) is equal to the average annual flow that can be used by the turbine to produce energy. The average annual energy is:

Area OABCDEF x Hn x 6.9 x 8760 kW.h

All flows greater than B cannot be used to produce energy.

In the second example, Figure C(B) the turbine is sized so that its maximum flow equals the flow in the stream that is available 60 percent of the time (i.e. Point C).

The minimum turbine flow is $\frac{C}{2} = \frac{B}{2} = A = D$.

This minimum flow is available only 85 percent of the time (Point D), and any flow less than this, represented by the area DEFG, cannot be used by the turbine. The average annual energy that can be generated by this turbine is:

Area OABCDG x Hn x 6.9 x 8760 kW.h

TABLE A

QUINSAM RIVER NEAR CAMPBELL RIVER - STATION NO 08HD005

DAILY DISCHARGE IN CUBIC METRES PER SECOND FOR 1983

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	8.00 E	12.0	12.2 E	12.7	5.74	3.00	3.27	2.41	2.30	3.31	6.21	5.11	1
2	10.0 E	10.3	9.00 E	13.3	5.02	3.71	3.13	2.36	2.47	3.20	6.37	6.09	2
3	10.9 A	9.05	8.00 A	11.6	6.00	3.47	3.16	2.34	2.50	3.25	7.78	7.41	3
4	11.2 E	8.31	7.71 A	10.3	6.14	3.18	3.13	2.29	2.65	3.21	8.27	6.86	4
5	10.1 A	7.12	8.00 A	9.16	5.71	3.04	3.06	2.26	3.06	3.24	10.3	5.86	5
6	10.0 E	7.03	7.22 A	8.27	5.12	3.01	3.01	2.20	2.90	3.27	12.8	5.04	6
7	9.42 A	8.00	8.40 A	7.43	4.86	3.04	2.90	2.15	3.61	3.13	13.8	5.21	7
8	11.9	8.57	10.5 A	6.56	4.87	2.77	2.80	2.21	3.72	3.13	12.5	5.32	8
9	14.7	9.56	20.3 A	6.16	4.52	2.80	2.75	2.19	3.76	3.15	12.0	5.37	9
10	15.3	8.94	41.7 A	5.66	4.12	3.10	2.75	2.00	5.36	3.10	13.7	5.15	10
11	22.6	42.0	31.0 A	5.70	3.82	3.03	2.80	2.02	4.09	3.10	20.9	5.29	11
12	33.7	51.3 A	30.0 A	5.48	3.47	3.27	3.36	1.95	4.56	3.16	28.5	7.76	12
13	35.9	82.0 E	34.5 E	5.23	3.97	3.18	3.95	1.97	4.33	3.21	30.8	12.3	13
14	30.6	46.0 E	41.0 A	4.94	4.00	3.04	4.20	1.94	3.90	3.20	62.0	10.5	14
15	21.9	31.0 E	34.6 A	4.55	4.06	2.97	4.22	1.91	3.60	3.19	80.0	9.66	15
16	15.7	25.0 E	30.5 A	4.34	3.76	2.79	4.06	1.91	3.31	3.01	56.7	8.00	16
17	12.6	21.6 E	50.6 A	4.15	3.85	2.80	3.72	1.91	3.11	2.92	54.9	7.00	17
18	14.5	25.0 E	12.6 A	4.06	3.57	2.71	3.42	1.90	3.02	2.70	48.5	6.40	18
19	18.6	20.0 E	10.5	4.03	3.70	2.66	3.10	1.89	2.92	2.76	35.8	6.35	19
20	17.3	16.3 E	9.32	4.15	3.87	2.64	3.00	1.87	2.92	2.80	26.5	5.07	20
21	15.0	12.3 E	8.10	4.60	4.20	2.86	3.25	1.66	2.90	3.46	22.3	4.40	21
22	13.6	20.0 E	7.23	4.55	4.28	2.87	3.28	1.64	2.86	5.49	18.1	3.97	22
23	11.6	25.0 E	6.53	4.57	4.20	2.86	3.15	1.66	3.09	5.53	14.8	3.78	23
24	15.1	22.5 E	6.10	5.00	4.62	2.84	3.01	1.64	3.59	5.20	15.7	3.87	24
25	19.7	22.5 E	5.85	5.01	4.82	2.61	2.92	1.61	3.94	5.00	15.1	3.92	25
26	36.4	20.0 E	4.89	5.23	4.30	2.87	2.67	1.42	3.90	6.06	16.2	4.17	26
27	48.4	17.5 E	4.60	5.16	3.97	2.80	2.61	1.62	3.83	9.93	14.5	4.10	27
28	41.6	13.5 E	5.37	5.02	3.70	2.97	2.71	2.06	3.76	10.3	12.9	3.95	28
29	25.3		9.06	5.51	4.01	2.90	2.59	2.52	3.57	9.06	11.6	3.86	29
30	18.0		11.7	5.02	4.37	3.03	2.67	2.07	3.43	7.64	10.1	4.01	30
31	16.1		11.7		4.10		2.50	2.10		6.21		4.20	31

MONTHLY AND ANNUAL MEAN DISCHARGES IN CUBIC METRES PER SECOND FOR THE PERIOD OF RECORD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	YEAR
1956	---	---	---	---	---	---	---	1.63	1.33	9.83	12.8	17.8	---	1956
1957	7.34	6.40	15.2	11.9	6.31	2.85	2.05	3.95	2.76	2.09	4.34	14.5	6.70	1957
1958	21.1	23.1	8.77	8.65	5.61	3.17	1.89	1.66	2.09	8.92	7.07	21.6	9.30	1958
1959	20.9	7.96	10.6	7.72	9.51	6.99	3.85	1.73	2.37	4.62	8.91	14.5	8.33	1959
1960	8.02	10.1	5.71	9.79	7.09	6.91	2.58	1.83	1.82	5.32	9.73	16.6	7.82	1960
1961	30.3	27.8	22.3	12.5	12.3	5.95	3.23	2.08	2.39	3.45	7.83	10.3	11.6	1961
1962	13.7	12.8	7.64	6.53	5.72	8.07	2.62	3.00	3.05	11.1	21.8	32.5	10.6	1962
1963	12.3	19.2	11.1	9.54	6.99	2.73	3.16	3.35	3.00	13.9	19.9	19.7	10.6	1963
1964	10.0	14.3	8.33	5.22	4.16	8.00	4.50	3.16	3.07	4.29	5.97	8.55	7.29	1964
1965	8.39	15.5	8.08	6.90	4.28	2.87	2.37	2.19	2.11	7.58	14.6	22.1	8.04	1965
1966	16.2	12.4	16.4	7.52	5.10	6.11	2.87	2.33	3.08	4.47	15.8	30.2	10.6	1966
1967	17.2	11.5	16.0	7.19	5.90	6.35	1.88	1.72	2.80	9.82	9.11	21.7	9.11	1967
1968	40.5	12.4	13.5	4.91	5.06	3.36	2.46	2.27	3.99	16.8	25.2	22.3	13.5	1968
1969	5.70	12.3	13.9	10.9	7.30	3.69	2.27	2.20	4.10	5.00	15.4	23.8	9.14	1969
1970	8.66	9.52	6.43	5.07	4.29	2.89	1.60	1.80	3.22	3.36	5.09	20.6	6.04	1970
1971	10.7	19.8	11.6	13.0	8.03	5.00	2.37	2.30	3.84	5.80	19.9	6.40	9.77	1971
1972	5.01	12.1	36.4	17.6	8.09	6.02	2.16	2.66	4.42	2.81	9.10	16.0	10.3	1972
1973	22.8	5.92	9.74	4.20	4.35	2.91	1.75	1.10	2.46	5.30	9.20	21.0	8.43	1973
1974	17.3	15.1	18.6	11.2	7.27	7.90	4.82	2.34	3.30	3.89	9.22	15.3	9.64	1974
1975	8.57	6.26	12.7	11.1	10.7	5.17	3.00	2.06	4.51	8.65	42.6	13.0	10.7	1975
1976	12.2	9.70	7.17	6.61	5.50	4.60	2.06	2.09	3.59	3.75	5.27	8.67	5.97	1976
1977	6.05	11.2	10.5	4.67	4.19	3.30	2.03	1.73	3.69	7.11	16.7	16.5	7.20	1977
1978	8.22	13.4	12.3	9.89	5.30	2.00	1.87	2.19	5.16	4.61	8.04	8.13	6.70	1978
1979	6.32	19.1	11.8	7.69	6.22	2.20	1.82	1.68	4.77	8.09	5.83	19.1	7.65	1979
1980	7.00	10.6	11.6	8.12	4.30	6.17	4.09	1.89	3.76	4.61	12.2	29.9	8.61	1980
1981	12.7	11.9	5.03	5.74	6.69	4.82	2.74	2.14	3.75	6.52	11.8	12.8	7.15	1981
1982	7.66	12.9	12.0	6.67	5.27	4.03	2.00	1.85	3.36	13.1	7.38	15.9	7.69	1982
MEAN	10.2	13.5	12.0	8.64	6.03	4.47	2.67	2.34	3.25	6.86	12.6	18.4	8.76	MEAN

LOCATION - LAT 50 01 45 N
LONG 125 17 55 W

DRAINAGE AREA, 280 km^2
REGULATED

ANNUAL EXTREMES OF DISCHARGE AND ANNUAL TOTAL DISCHARGE FOR THE PERIOD OF RECORD

YEAR	MAXIMUM INSTANTANEOUS DISCHARGE (m^3/s)	MAXIMUM DAILY DISCHARGE (m^3/s)	MINIMUM DAILY DISCHARGE (m^3/s)	TOTAL DISCHARGE (dam^3)	YEAR
1956	—	—	[illegible] ON [illegible] 21 *	—	1956
1957	—	30.3 ON DEC 26	1.35 ON OCT 15	214 000	1957
1958	—	64.6 ON DEC 3	1.47 ON AUG 17	296 000	1958
1959	—	63.6 ON JAN 12	1.64 ON AUG 16	263 000	1959
1960	—	52.2 ON DEC 14	1.66 ON SEP 16	247 000	1960
1961	—	110 E ON JAN 12	1.90 ON AUG 10	364 000	1961
1962	—	67.6 ON DEC 6	2.12 ON AUG 1	327 000	1962
1963	—	71.9 ON DEC 24	2.30 ON JUN 29	326 000	1963
1964	—	30.6 ON JAN 4	2.04 ON AUG 24	230 000	1964
1965	—	54.0 ON DEC 4	1.97 ON AUG 2	254 000	1965
1966	—	74.8 ON DEC 6	2.04 ON AUG 25	335 000	1966
1967	—	38.2 ON DEC 7	1.50 ON JUL 16	288 000	1967
1968	—	[illegible] ON JAN 17 *	1.93 ON AUG 4	426 000	1968
1969	—	61.7 ON DEC 11	1.56 ON AUG 1	288 000	1969
1970	—	84.2 ON DEC 18	1.22 ON FEB 28	190 000	1970
1971	—	96.3 ON NOV 10	1.85 ON AUG 11	308 000	1971
1972	—	79.9 ON MAR 16	1.66 ON AUG 1	325 000	1972
1973	—	91.7 ON JAN 16	0.963 ON AUG 10	266 000	1973
1974	—	65.4E ON JAN 16	1.74 ON AUG 19	304 000	1974
1975	—	188 ON NOV 14	1.19 ON AUG 1	337 000	1975
1976	—	26.3 ON JAN 31	1.73 ON AUG 10	189 000	1976
1977	—	63.1 ON DEC 3	1.18 ON AUG 22	230 000	1977
1978	—	30.6 ON NOV 6	1.23 ON JUL 27	214 000	1978
1979	—	70.5 ON DEC 19	1.05 ON JUL 1	241 000	1979
1980	—	76.5 ON DEC 12	1.51 ON AUG 12	272 000	1980
1981	40.6 ON JAN 22	38.5E ON JAN 22	1.82 ON AUG 21	225 000	1981
1982	61.4 AT 21:30 PST ON OCT 25 *	56.0 ON OCT 26	1.69 ON JUL 28	243 000	1982
MEAN				277 000	MEAN

E - ESTIMATED

* - EXTREME RECORDED FOR THE PERIOD OF RECORD

TABLE A (A)

FLOW m^3/s	No. OF OCCURRENCES 1983	TOTAL	ACCUM TOTAL	% OF TOTAL
0 - 1.0				
1.0 - 1.5		0	365	100
1.5 - 2.0	16,	0	365	100
2.0 - 2.5	12, 1,	16	365	100
2.5 - 3.0	4, 15, 5, 5, 2, 3, 4,	13	349	95.6
3.0 - 4.0	3, 5, 2, 5, 5, 7, 2, 8, 10, 5, 25, 1, 4, 2,	38	336	92.1
4 - 5	2, 10, 4, 2, 6, 3, 3, 3, 1, 2, 2	84	298	81.6
5 - 7	2, 1, 3, 1, 6, 12, 1, 5, 3, 8, 3,	39	214	58.6
7 - 10	2, 2, 4, 2, 3, 2, 3, 1, 3, 1, 2, 2, 3, 1, 3,	45	175	47.9
10 - 15	3, 2, 2, 3, 3, 1, 2, 1, 2, 6, 1, 6, 1, 5, 2,	34	130	35.6
15 - 20	1, 1, 2, 2, 1, 2, 1, 2, 1, 2,	40	96	26.3
20 - 40	5, 1, 1, 4, 3, 1, 3, 2, 3, 3,	15	56	15.3
40 - 80	2, 1, 2, 1, 1, 1, 5,	27	41	11.2
90 - 150	1	13	14	3.8
150 UP		1	1	0.3
	Total	365		

TABLE A (B)

COLUMN No. 1	2	3	4	5	6	7	8	9
FLOW m^3/s	No. OF OCCURRENCES IN EACH YEAR					TOTAL	ACCUM. TOTAL	% OF TOTAL
	1979	1980	1981	1982	1983			
0 - 1.0	0	0	0	0	0			
1.0 - 1.5	5	0	0	0	0			
1.5 - 2.0	10	10	15	14	16	5	1826	100
2.0 - 2.5	12	21	20	20	13	65	1821	99.7
2.5 - 3.0	30	40	30	80	38	86	1756	96.2
3.0 - 4.0	90	40	70	50	84	218	1670	91.4
4 - 5	50	75	60	40	39	324	1452	79.5
5 - 7	47	60	55	45	45	264	1128	61.8
7 - 10	42	36	30	30	34	252	864	47.3
10 - 15	35	44	40	35	40	172	612	33.5
15 - 20	20	20	25	20	15	194	440	24.1
20 - 40	25	10	20	19	27	100	246	13.5
40 - 80	9	10	0	12	13	101	146	8.0
80 - 150	0	0	0	0	1	44	45	2.5
150 UP						1	1	0
Totals	365	366	365	365	365	1826		

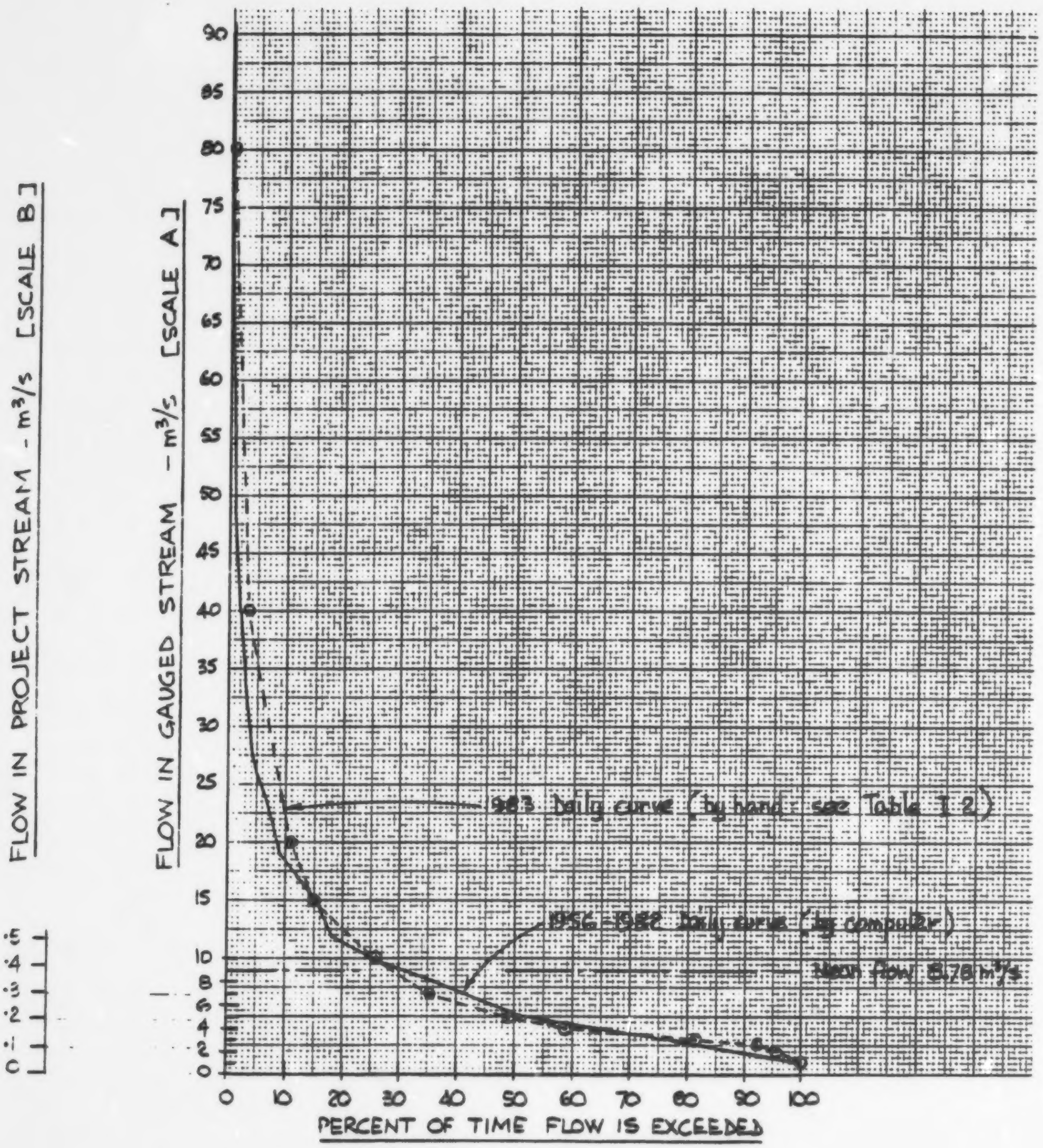


FIG A FLOW-DURATION CURVES

TABLE OF MEASURED FLOWS

DATE	PROJECT STREAM m³/s	GAUGED STREAM m³/s
1984		
July 3	·110	2·41
5	·110	2·37
7	·107	2·29
8	·104	2·07
10	·092	2·14
11	·089	2·13
13	·085	2·05
14	·087	1·94
16	·078	1·82
23	·063	1·70
27	·055	1·63
31	·048	1·62

TABLE OF EQUIVALENT FLOWS

PROJECT STREAM m³/s	GAUGED STREAM m³/s
0·1	2·2
0·2	4·5
0·3	6·8

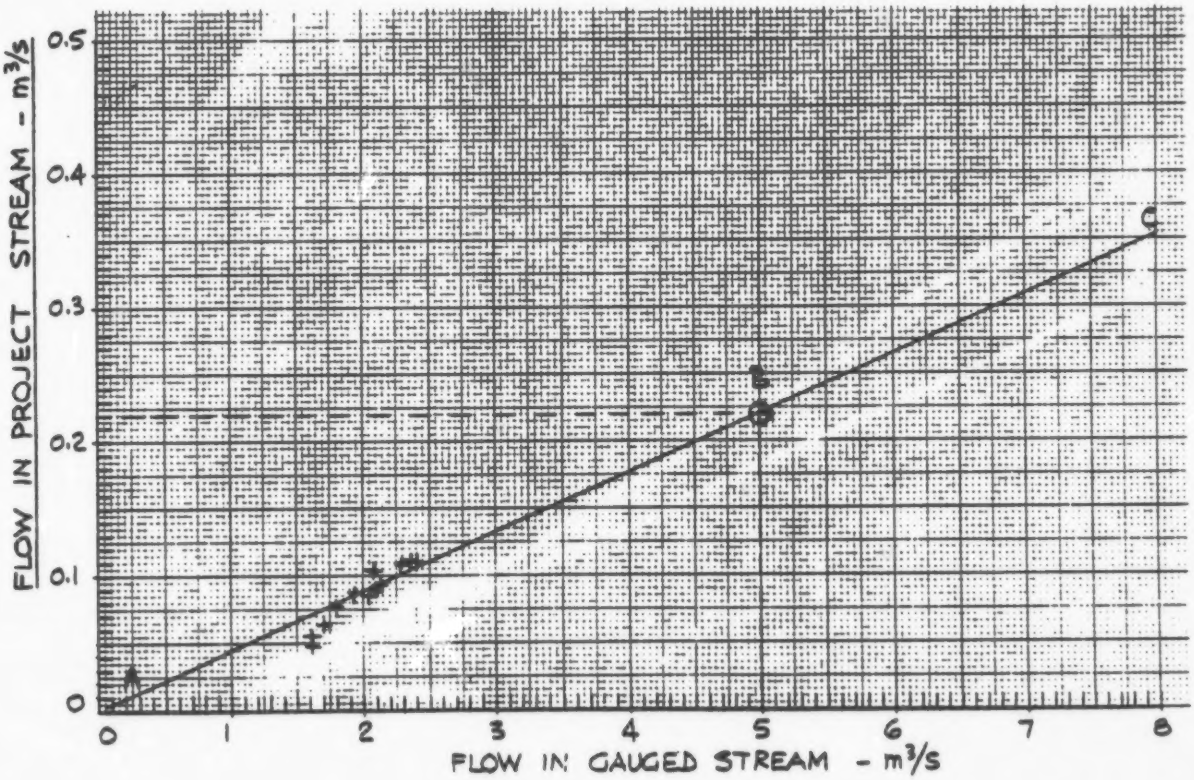
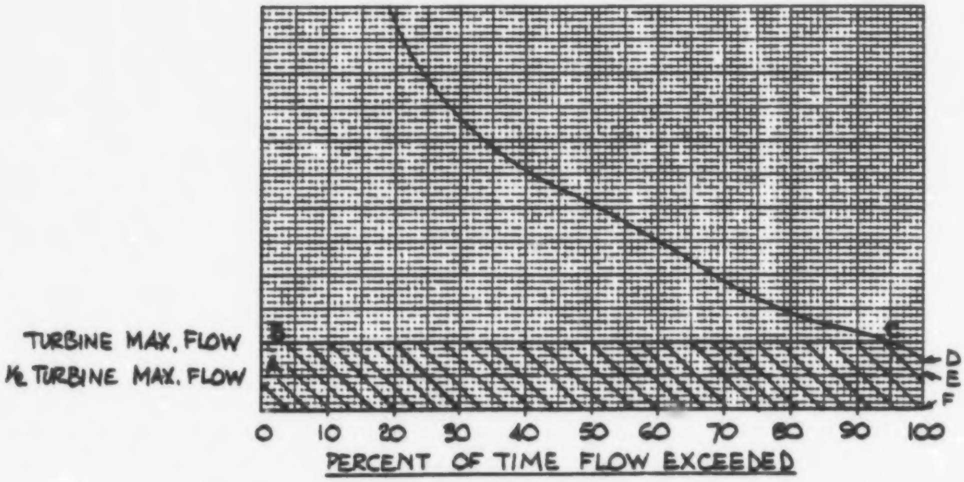
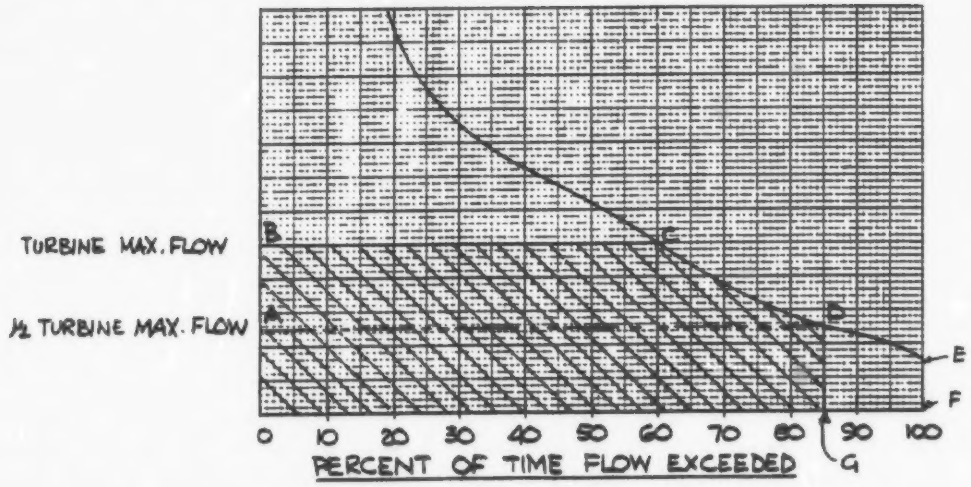


FIG B



A. PLANT SIZED FOR 95% EXCEEDANCE FLOW



B. PLANT SIZED FOR 60% EXCEEDANCE FLOW

FIG C EXAMPLES OF USE OF FLOW-DURATION CURVES

SUPPLEMENT 3.2

CALCULATING RESERVOIR STORAGE

1 PLOTTING MASS CURVE

1.1 Introduction

This appendix describes how to plot a mass curve, and how to use it to calculate the amount of storage required to keep your hydrom plant running through the low-flow periods. The method involves a lot of simple calculations which can be done with a hand calculator. If you have a computer you could write a programme to do the calculations.

If you don't want to do the calculations yourself you could hire an engineer for the specific task of calculating the amount of storage you require, and the height of the storage dam that you need. If the dam is higher than about 2m it should be designed by an engineer.

1.2 How to Draw a Mass Curve

1.2.1 Calculating Average Turbine Flow

First you need to calculate the flow that is required to produce power from the hydro plant - call this the "turbine flow". Equation 3-3 in Chapter 3, can be rewritten as:

$$Qt = \frac{P}{Hn \times 6.9} \ m^3/s \qquad 1$$

where Qt = flow in m^3/s
P = power output of generator in kW
Hn = net head in metres (See Chapter 3, Section 3.4.1, on how to calculate net head.)

The average monthly turbine flow is needed for selecting the low-flow period that will be used to calculate storage. The turbine flow calculated from equation 1 above is the maximum flow needed to generate maximum power. However, the hydro plant won't be generating maximum power all the time -- as discussed is Chapter 1, Section 1.6.4 -- and a Plant Factor (PF) can be used to estimate the average monthly turbine flow.

If the lowest flows occur in the summer and the peak summer loads are not the maximum for the year, use a PF of 60 percent. If the lowest flows are in the winter and the maxumum loads occur in winter, use a PF of 90 percent.

The average monthly turbine flows will be:

Qt x 0.6 in the summer, or
Qt x 0.9 in the winter.

1.2.2 Selecting the Low-Flow Period

At least ten years of flow records are needed to make the storage calculations meaningful. If you don't have ten years of flow records on your project stream, you can use the flow records of a nearby gauged stream and make adjustments as explained below.

First read Supplement 3.1, Section 1.1, to find out how to select a suitable gauged stream to use, and the select one.

Next, estimate what the average monthly turbine flow would be is you assumed that your hydro plant was on the Gauged Stream. This is easier to do than converting all the Gauged Stream flows to represent flows in the Project Stream, that is, the stream on which you build your project. Assume that the flows in the Project Stream and the Gauged Stream are proportional to the stream's drainage areas. Thus, the turbine flow for the Gauged Stream will be:

$$Qtg = Qt \times \frac{\text{drainage area of Gauged Stream}}{\text{drainage area of Project Stream}}$$

where Qtg = average monthly flow for the Gauged Stream, in m^3/s
Qt = average monthly turbine flow for the Project Stream in m^3/s

Next, get a copy of the streamflow records titled "Monthly and Annual Discharges in Cubic Metres per Second for the Period of Record" for the selected Gauged Stream. Supplement 2.1, Section 3.2 tells you where to get streamflow data, and Supplement 3.1, Table I-1 shows an example of the data.

The method of selecting the low-flow period from which to calculate the storage required is illustrated by the following example.

Example:

Drainage area of Project Stream = 12.5 km^2
Drainage area of Gauged Stream (Quinsam River) = 280 km^2
Average monthly turbine flow for Project Stream
Qt = 0.106 m^3/s

Equivalent average monthly turbine flow for Gauged Stream:

$$Qtg = 0.106 \times \frac{280}{12.5} = 2.37\ m^3/s$$

Use the "Monthly and Annual Mean Discharges in Cubic Metres per Second for the Period of Record" for the Quinsam River, shown in Table A(A).

1. Find the first month in each year that the flow was less than Qtg = 2.37 m^3/s. Enter these flows in a table similar to Table A(B), column 2. Ignore years when all flows were greater than 2.37 m^3/s.

2. Calculate the average of the first month (found in Step 1) and the month following it, and enter this two-month average in column 3 of the table.

3. If any of the 2-month averages (Step 2) are less than Qtg, add a third month and calculate the three-month average.

4. Repeat, adding one month at a time and averaging the flows for each 4-month, 5-month, etc., period until the average is greater than Qtg.

When the average flow for a period is greater than Qtg, the total flow for that period will be sufficient to run the turbine all the time provided that there is sufficient storage to even out the flow.

5. Select the lowest value in each of columns 2, 3, 4, etc. in the table. Normally, these are the periods for which mass curves should be plotted.

   For continuing the example a mass curve will be plotted for 1973 -- this year had the lowest two-month and three-month average flows as well as the lowest single month in the whole record, that is August 1973.

1.2.3 Calculating Values for the Mass Curve

The mass curve is a plot of cumulative flows: each point on the curve represents the total flow that has occured since a selected day.

Five-day average flows are used for plotting the mass curve. Using daily flows would be a lot more work and wouldn't improve the accuracy of the results, while using monthly average flows could give a storage value that is too low.

To calculate cumulative flows follow the steps below:

1. Get a copy of the daily discharges for the selected Gauged Stream and the selected year.

   Example: Quinsam River, 1973, shown in Table B(A). Note that the flows are in cubic feet per second (cfs) which is the way flows were measured and published before 1979.

2. Draw up a table like the one in Table B(B). Starting on July 1, 1973, add each group of five daily flows in Table B(A), and enter the five-day totals in Table B(B), column 2.

   Example: July 1-5, total flow was 352 cfs-days.
   July 6-10, total flow was 334 cfs-days.

3. Starting at the top of Table B(B), column 2, add each five-day flow to the previous value and enter in Table B(B), column 3.

   Example: At end of July 5, total flow was 352 cfs-days.
   At end of July 10, total flow was 352 + 334 = 686 cfs-days.

4. Convert the cumulative flows in the Gauged Stream (column 3) to equivalent flows in the Project Stream (column 4).

   Two methods for converting flows from one stream to represent flows in another stream are discussed in Supplement 3.1, Section 2.0. In this example the ratio of the drainage areas of the two streams is used.

   Example: Let flow in Project Stream by Q_p
   Let flow in Gauged Stream be Q_g
   Then:

$$Q_p = Q_g \times \frac{\text{drainage area of Project Stream}}{\text{drainage area of Gauged Stream}}$$

$$Q_p = Q_g \times \frac{12.5}{280}$$

   To convert flow in cfs-days to m^3/s-days divide by 35.3

$$Q_p = Q_g \times \frac{12.5}{280 \times 35.3}$$

$$= Q_g \times 0.00126$$

   Multiply values in Table B(B), column 3 by 0.00126 to get the equivalent flows in the Project Stream, and write the values in column 4.

1.2.4 Plotting a Mass Curve

Figure A shows the mass curve for the Project Stream. It was drawn by plotting the values in Table B(B) column 4, against the last day of the five-day period in column 1.

Plot your values the same way.

1.3 Using a Mass Curve to Find Storage

Look at the mass curve in Figure A. Imagine you already have a storage reservoir on the Project Stream. The mass curve shows, at any time, the total volume of water that has flowed into your reservoir -- call this the inflow. The line AB shows, at any time, the total volume of water that has been used by the turbine -- call this the turbine flow. The vertical distance between the mass curve and line AB shows the difference between the inflow volume and the turbine flow volume. If the turbine flow volume is greater than the inflow volume, the difference will have to come from storage. In Figure A, the greatest vertical distance between the turbine flow line, AB, and the mass curve of inflow, shows the greatest volume of storage needed to keep the turbine running through this dry period.

If the mass curve is above the turbine flow line (eg. in Figure A, to the right of B), there has been more inflow than was needed for the turbine, and flow will be spilled out of the reservoir.

Example:

Turbine flow = 0.106 m^3/s
To draw line AB calculate the total turbine flow volume during the period July 1 to October 31
= 0.106(31+31+30+31) = 13.04 m^3/s-days

In Figure J.1, plot the point C at 13.04 m^3/s-days on October 31. Draw a straight line from zero on July 1 to point C. This line intersects the mass curve of inflow at B.

The greatest vertical distance between line AB and the mass curve is 2.9 m^3/s-days.

The volume of storage needed is this value multiplied by the number of seconds in a day, ie. 86400.

Therefore, the volume of storage needed is 2.9 x 86400 = 250,560 m^3.

TABLE A –

A. MONTHLY AND ANNUAL MEAN DISCHARGES FOR THE QUINSAM RIVER

QUINSAM RIVER NEAR CAMPBELL RIVER - STATION NO. 08HD005

MONTHLY AND ANNUAL MEAN DISCHARGES IN CUBIC METRES PER SECOND FOR THE PERIOD OF RECORD

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	YEAR
1956	---	---	---	---	---	---	---	1.63	1.33	9.83	12.8	17.8	---	1956
1957	7.34	6.40	15.2	11.9	6.31	3.85	2.85	3.95	2.76	2.49	4.36	14.5	6.70	1957
1958	21.1	23.1	8.77	8.65	5.41	3.17	1.89	1.64	3.04	8.92	7.07	21.6	9.38	1958
1959	20.9	7.96	10.6	7.73	9.51	6.99	3.03	1.73	2.37	4.62	8.91	14.5	8.33	1959
1960	8.82	10.1	5.71	2.79	7.09	6.91	2.58	1.83	1.82	5.32	9.73	16.6	7.02	1960
1961	30.3	27.8	22.3	13.5	12.3	5.95	3.23	2.04	2.39	3.45	7.03	10.3	11.6	1961
1962	13.7	12.8	7.04	6.53	5.72	4.07	2.62	3.88	3.05	11.1	21.8	22.3	10.4	1962
1963	12.3	19.2	11.1	9.34	6.99	2.73	3.16	3.35	3.89	13.9	19.9	19.7	10.4	1963
1964	18.8	14.3	8.33	5.22	4.16	8.08	4.34	3.16	3.07	4.29	5.97	8.55	7.29	1964
1965	8.39	15.5	8.08	6.90	4.28	2.87	2.37	2.19	2.11	7.50	14.8	22.1	8.04	1965
1966	16.2	12.4	14.6	7.52	3.10	4.11	3.07	2.33	3.08	4.47	15.8	39.2	10.6	1966
1967	17.2	11.5	16.8	7.19	5.90	4.35	1.88	1.72	2.80	9.82	9.11	21.7	9.11	1967
1968	48.5	12.4	13.5	4.91	5.46	3.36	2.96	2.27	3.99	16.8	25.2	22.3	13.5	1968
1969	5.70	12.3	13.9	14.9	7.38	3.69	2.27	2.20	4.10	5.00	15.4	23.8	9.14	1969
1970	8.66	9.32	6.43	3.87	4.29	2.89	1.60	1.88	3.22	3.36	5.89	20.6	6.09	1970
1971	18.7	19.8	11.6	13.6	8.83	5.00	2.37	2.50	3.84	5.80	19.9	6.48	9.77	1971
1972	5.01	12.1	36.8	17.4	8.49	6.82	2.16	2.66	4.42	2.81	9.10	16.0	10.3	1972
1973	22.4	5.92	9.74	4.20	6.35	3.51	1.75	1.18	2.96	5.34	9.28	31.0	8.43	1973
1974	17.3	15.1	18.4	11.2	7.27	7.90	4.82	2.34	3.38	3.89	9.22	15.3	9.64	1974
1975	8.57	6.26	12.7	11.1	18.7	5.17	3.09	2.46	4.31	8.65	42.6	13.8	10.7	1975
1976	13.2	9.70	7.17	6.61	3.56	4.68	2.46	2.09	3.59	3.75	5.27	8.67	5.97	1976
1977	6.05	11.2	10.5	4.67	4.19	3.20	2.03	3.73	3.69	7.11	16.7	16.5	7.28	1977
1978	8.23	13.4	12.3	9.89	5.30	2.88	1.47	2.19	5.16	4.61	8.44	8.13	6.78	1978
1979	4.32	10.1	11.8	7.69	6.22	2.20	1.82	1.68	4.77	8.09	3.83	19.1	7.65	1979
1980	7.08	10.6	11.4	8.12	4.30	4.17	4.49	1.89	3.76	4.61	12.2	29.9	8.61	1980
1981	12.7	11.8	5.83	5.74	6.69	4.82	2.76	2.14	3.75	6.52	11.8	12.8	7.15	1981
1982	7.66	12.9	12.4	6.67	5.27	4.83	2.04	1.85	3.36	13.1	7.38	15.9	7.69	1982
MEAN	14.2	13.5	12.4	8.64	6.43	4.67	2.67	2.24	3.25	6.86	12.6	18.4	8.78	MEAN

LOCATION - LAT 50 01 45 N DRAINAGE AREA, 280 km²
LONG 125 17 55 W REGULATED

B. SUMMARY OF LOW-FLOW PERIODS

1	2	3	4	5
YEAR	AVERAGE FLOWS - m³/s			
	1-MONTH	2-MONTH	3-MONTH	4-MONTH
1958	1.89 July	1.77	1.86	3.11
1960	1.83 Aug	1.83	2.99	
1961	2.04 Aug	2.22	2.63	
1965	2.37 July	2.28	2.22	3.56
1966	2.33 Aug	2.71		
1967	1.88 July	1.80	2.13	4.05
1968	2.27 Aug	3.13		
1969	2.27 July	2.24	2.88	
1970	1.60 July	1.74	2.23	2.51
1971	2.37 July	2.43		
1972	2.16 July	2.41		
1973	1.75 July	1.47	1.80	2.68
1974	2.34 Aug	2.82		
1976	2.09 Aug	2.84		
1977	2.03 July	2.88	2.48	
1978	1.47 July	1.83	2.94	
1979	2.20 June	2.01	1.90	2.61
1980	1.89 Aug	2.83		
1981	2.14 Aug	2.95		
1982	2.04 July	1.95	2.41	

TABLE B

A. DAILY DISCHARGES IN QUINSAM RIVER IN 1973

QUINSAM RIVER NEAR CAMPBELL RIVER - STATION NO. 08HD005

DAILY DISCHARGE IN CUBIC FEET PER SECOND FOR 1973

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	673	360	445	192	143	123	64.8	44.8	63.2	145	333	409
2	655	368	400	180	159	117	71.8	44.8	63.2	125	281	468
3	625	380	427	172	182	117	71.8	41.2	64.8	125	242	589
4	508	360	445	167	180	121	71.8	40.0	64.8	123	190	644
5	455	305	441	167	177	123	71.8	37.0	64.8	115	177	550
6	330	255	392	163	172	117	68.0	37.0	66.4	103	163	853
7	213	222	380	151	172	115	66.4	36.0	66.4	103	177	1370
8	150	210	380	157	153	105	66.4	36.0	69.9	123	252	1230
9	142	207	321	151	145	99.0	66.4	36.0	69.9	123	337	1170
10	170	192	305	153	137	101	66.4	34.0	68.0	123	432	1190
11	182	187	248	151	125	97.0	66.4	34.0	68.0	123	486	1510
12	190	167	239	147	115	97.0	66.4	35.0	68.0	123	486	2090
13	355	163	222	149	111	99.0	66.4	35.0	68.0	125	529	2170
14	625	157	216	147	117	105	64.8	35.0	66.4	123	486	2280
15	1690	151	219	151	117	103	64.8	37.0	66.4	121	463	1640
16	3240	155	222	159	180	105	63.2	38.0	66.4	121	396	1130
17	2560	155	445	159	185	105	63.2	37.0	69.9	145	337	1010
18	1690	157	600	147	185	109	61.6	40.0	69.9	198	301	1090
19	1410	157	720	147	175	115	61.6	40.0	75.6	219	337	1270
20	1230	155	628	137	147	113	61.6	40.0	75.6	252	301	1650
21	975	153	468	131	137	111	60.0	41.2	85.1	219	311	2060
22	720	151	400	127	137	107	58.4	46.0	95.0	190	285	1650
23	898	151	329	129	165	103	55.2	41.2	105	185	255	1400
24	1320	153	229	127	180	103	53.6	40.0	125	187	245	928
25	1280	151	229	131	222	95.0	53.6	40.0	135	182	239	755
26	305	155	222	133	163	85.1	53.6	39.0	135	219	242	622
27	341	153	222	131	147	83.2	53.6	50.8	135	258	288	477
28	445	321	225	127	145	77.5	53.6	50.8	145	356	360	463
29	468		216	133	137	68.0	50.8	63.2	145	540	380	405
30	341		210	137	127	66.4	50.8	63.2	145	418	427	376
31	360		216		125		46.0	63.2 E		337		348
TOTAL	24546	5851	10661	4453	4762	3085.2	1914.8	1296.4	2605.7	5849	9738	33897
MEAN	792	209	344	148	154	103	61.8	41.8	86.9	189	325	1090
AC-FT	48700	11600	21100	8830	9450	6120	3800	2570	5170	11600	19300	67200
MAX	3240	380	720	192	222	123	71.8	63.2	145	540	529	2280
MIN	142	151	210	127	111	66.4	46.0	34.0	63.2	103	163	348

B. CUMULATIVE 5-DAY FLOWS IN PROJECT STREAM

1	2	3	4			
	JULY			AUGUST		
DATE	5-DAY FLOW QUINSAM CFS-DAYS	CUMULATIVE FLOW QUINSAM CFS-DAYS	CUMULATIVE FLOW PROJECT ST. M³/S-DAYS	5-DAY FLOW QUINSAM CFS-DAYS	CUMULATIVE FLOW QUINSAM CFS-DAYS	CUMULATIVE FLOW PROJECT ST. M³/S-DAYS
1-5	352	352	.44	208	2123	2.68
6-10	334	686	.87	179	2302	2.91
11-15	329	1015	1.28	176	2478	3.13
16-20	311	1326	1.68	195	2673	3.38
21-25	281	1607	2.03	208	2881	3.64
26-31	308	1915	2.42	330	3211	4.06
	SEPTEMBER			OCTOBER		
1-5	321	3532	4.47	633	6450	8.15
6-10	341	3873	4.90	575	7025	8.88
11-15	337	4210	5.32	615	7640	9.66
16-20	357	4567	5.77	935	8575	10.84
21-25	545	5112	6.46	963	9538	12.06
26-30/31	705	5817	7.35	2128	11666	14.76

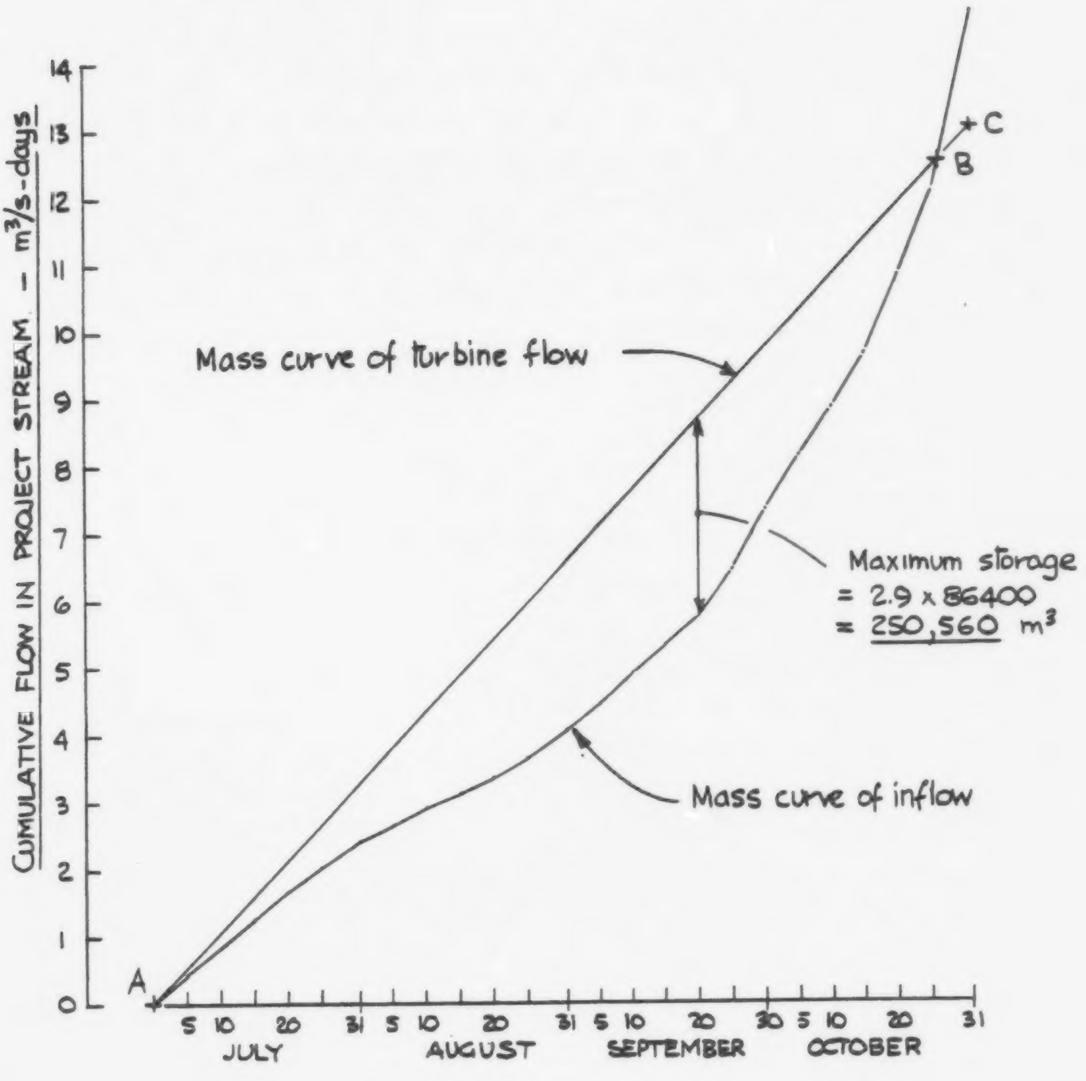


FIG A MASS CURVE

SUPPLEMENT 3.3

INFORMATION FROM TURBINE-GENERATOR MANUFACTURERS AND SUPPLIERS

1 INFORMATION REQUEST FORMS

Use the "Turbine-Generator Manufacturer/Supplier Information Request Forms, Parts I and II" at the end of Supplement 3.1, to provide the equipment manufacturers or suppliers with the information they need.

Fill out Part 1 and send a blank copy of Part II for the manufacturer or supplier to complete. Send the forms to at least three manufacturers so that you have some prices to compare. Also, different manufacturers might have different ideas about how to develop your hydro project.

An explanation of Part I is given below.

PART 1

A Reason for Development

Check one of items 1 to 5, or add a more appropriate explanation. This will enable the supplier to decide what type of generator, speed control equipment, and switchgear you need.

Chapter 4, Sections 4.2.2 and 4.2.4, explains how induction and synchronous generators work and how each should be used.

B Existing Structures and Equipment

If there is, or has been, a hydro plant at the site, describe the structures and say how you would like to use them. Or, if you have some electrical or mechanical equipment (eg. turbine, pump, generator, pipe, etc.), describe it.

C Head and Pipeline

Give the head and length of pipeline which you measured in Chapter 2.

D Flow

Give the flow data that you have measured with your weir, and any other data that you have calculated or gathered from from government agencies. If you want to generate maximum power year-round, the plant should be designed for the minimum flow (check item D3)

E Electrical Power Needs

Send the Load Inventory - Table 3.2; and one or more Daily Load Logs - Table 3.4.

The information on alternative energy sources for space heating, water heating, and cooking is given because these use large amounts of power and it might be more economical not to convert the alternative sources to electricity - as discussed in Chapter 3, Section 3.3.

F Additional Information

A photocopy of a portion of a topographical map of the area, with the location of the hydro project marked on it, would be very helpful to the turbine supplier. A separate sketch showing the dam or intake, pipeline, power-house and load centre, with measured distances, would also be useful.

The information about the cost of electricity from a utility would enable the turbine supplier to check if it is economical to build the size of plant you have proposed.

Add any other information you think the turbine supplier might find useful.

TURBINE-GENERATOR MANUFACTURER/SUPPLIER INFORMATION REQUEST FORM

PART ONE

I intend to build a small hydro-electric plant, and I need estimates of the cost of the turbine, generator, and other electrical equipment. Please review the information given in Part I of this form, and fill out Part II and return it at your earliest convenience.

My name: ____________________
Address: ____________________
____
____
Phone No: ______________
Date: ______________

A REASON FOR DEVELOPMENT

(Check the boxes which are applicable)

☐ 1. I want electrical power year-round. The plant will be designed for the estimated minimum flow in the stream.

☐ 2. I want to generate power for my own use. I do not intend to connect to a utility; I need a synchronous generator.

☐ 3. I want to generate power for my own use. I want to sell excess power to a utility, but I also want to be able to generate independently from the utility. Therefore, I need a synchronous generator and speed control equipment.

☐ 4. I want to generate power to my own use. I want to sell excess power to a utility, and I will not be generating independently from the utility. An induction generator would be acceptable.

☐ 5. I want to generate the most power for the money I invest in the hydro-plant. I want to sell to a utility, but I want to be able to generate independently from the utility. I need a synchronous generator and speed control equipment.

☐ 6. I want to generate the most power for the money I invest in the hydro-plant, and sell power to a utility. I will not be generating independently from the utility; an induction generator would be acceptable.

☐ 7. Other reasons for development: (state how power will be used)

B EXISTING STRUCTURES AND EQUIPMENT

(Check one box)

☐ 1. There are no existing structures or equipment for a hydro plant at the site.

☐ 2. The following structures and equipment are available for building the hydro plant.

a. Dam:
Type When built Condition
Height .....m
Surface area of pond/reservoir upstream of dam ....km

b. Pipeline:
Material Length ......m
Diameter .....mm Wall thickness .....mm

c. Turbine:
Manufacturer Model No ....
Type Date of manufacture ....
Rated head ....m Rated speed ....rpm
Rated output ....HP/kw

d. Governor:
Manufacturer Model No ....
Date of manufacture ....

e. Generator:
Manufacturer Model No ....
Date of manufacture ....
Rated speed ....rpm Voltage ....
Rated output ......kVa Power factor ....

f. Other Equipment: (give details)

C HEAD AND PIPELINE DIMENSIONS

(Check where applicable)

1. The site has an existing dam; the gross head is:

☐ a) constant at ....m

☐ or b) varies from ....m to ......m

☐ 2. This will be a new project; a sketch of the layout is attached.

- ☐ a) The gross head will be ......m
  the pipeline length will be ......m
  the pipeline diameter will be ....mm

- ☐ b) An alternative layout has a gross head of ......m
  a pipeline length of ......m
  a pipeline diameter of ......mm

D FLOW

(Check where applicable)

☐ 1. I have measured flow in the stream from .... (date) to .... (date)

☐ The measured flows are attached.

☐ The monthly averages of the measured flows are attached.

☐ A flow-duration curve of measured flows is attached.

☐ The minimum measured flow was ....m^3/s

☐ 2. The estimated minimum flow is ....m^3/s;
it would occur in (month) ....

☐ 3. The plant should be designed for the minimum flow

☐ 4. The water in the stream is usually clear/muddy/carries a lot of silt.

5. Other flow data that might be useful:

E ELECTRICAL POWER NEEDS

(Check where applicable)

☐ 1. Information about my electrical power needs is given in the attached forms:

- ☐ a) Load Inventory
- ☐ b) Daily Load Logs

☐ 2. The estimated peak daily load in winter is ....kW;
The estimated peak daily load in summer is ....kW

☐ 3. I need a generator output of ....kW
the voltage should be ...... volts, single/three phase

☐ 4. I have alternative energy sources, as follows:

- ☐ a. Heating water (type: eg. wood, propane etc.)
- ☐ b. Space Heating (type)
- ☐ c. Cooking (type)

☐ 5. I want to install electric load management;
I have/could build the following load dumps:

☐ greenhouse; ☐ swimming pool; ☐ (other)

F ADDITIONAL INFORMATION

☐ 1. Site location: photo copy of topographical map with site marked on it is attached.
The name of the stream on which the hydro project will be built is ....

☐ 2. Name of the local electricity utility is ....
Distance to nearest transmission line ....km
The cost of installing electric service from the utility to my load would be $........
The cost of energy from the utility would be ....¢/kW.h

☐ 3. Extremes of air temperature are:
Maximum ....°C Minimum ....°C

G SKETCH OF HYDRO PROJECT

(Show stream, dam or pipeline intake, pipeline route, powerhouse, and the place where the power will be used; show distances measured along the ground.)

TURBINE-GENERATOR MANUFACTURER/SUPPLIER INFORMATION REQUEST FORM

PART TWO

Name of Company: ____________
Address: ____________
____
____

Phone No: ____________
Date: ____________

A GENERAL COMMENTS

B RECOMMENDED EQUIPMENT SUPPLIED BY COMPANY

1. Turbine Inlet Gate or Valve:
   Manufacturer — Model No.......
   Type

2. Turbine:
   Manufacturer — Model No.......
   Type

3. Generator:
   Manufacturer — Model No.......
   Type

4. Is governor included: Yes/No
   Yes: Type — Model No.......
   No: Type recommended — Model No.......

5. Additional items supplied with package, eg. transformer, protection devices, auxiliary equipment. Please give name of manufacturer, dimensions, operating characteristics.

C EQUIPMENT SPECIFICATION

For a net effective head at the turbine of ......m and a flow of ...... m^3/s, the generator output would be .....kW (assumed power factor of ......). The efficiency of the turbine-generator would be ......%.

Based on the information provided, the average annual energy production is calculated to be ....kW.h.

1. Turbine:
   Type of runner ....; diameter of runner .....mm.
   Speed at recommended head and flow given above is ....rpm.

2. Generator:
   Operating speed .....rpm   Overspeed allowance .....%
   Voltage .....single/three phase.
   Rating .....kVa single/three phase. Power factor .....

3. Speed Increaser:
   Type ....   Ratio .....
   Rated input horsepower .....   Service factor.....

4. Draft tube, if used:
   Distance between turbine runner centerline and tailwater at lowest water level .....m
   Length .....m   Outlet area .....m   Inlet diameter ..... mm.

5. Is unit assembled on equipment frame? Yes/No
   Yes: Dimensions of frame ....(m)

6. Recommended powerhouse minimum dimensions:
   Length .....m   Width .....m   Height .....m

7. Weight of assembled unit .....kg
   Shipping weight .....kg   Wetted weight .....kg
   Recommended mass of equipment pad .....kg

8. Is shutoff valve or gate provided upstream or turbine? Yes/No
   No: Recommended size
   Type .....   Manufacturer ....

9. Recommended spare turbine-generator parts

10. Expected operating life with normal maintenance and operating conditions: .....yrs

11. Turbine warranty provisions included? Yes/No

12. Is cooling water required for the generator, speed increaser, and/or lubrication system? Yes/No

    Yes: (Please give requirements)

13. Recommended powerhouse ventilation .....m^3/min

14. From information provided, the range of unit outputs would be:

    Minimum output .....kW, for net head of .....m, and flow of ..... m^3/s

    Maximum output .....kW, for net head of .....m, and flow of ..... m^3/s

15. Diameter of turbine inlet .....mm, and outlet .....mm, or outlet dimensions .....mm by .....mm.

16. Lightning protection is/is not provided.

D COST OF EQUIPMENT RECOMMENDED

(Check appropriate answers)

1. The cost of the recommended equipment delivered to the site is $......
   Bid is/is not attached.

2. On the basis of information provided, the cost of the equipment recommended should appraoch $....... delivered to the site. This is not a bid.

3. The cost estimates are good until ....

E ADDITIONAL INFORMATION

1. Delivery time for equipment is ....

2. Recommended material and equipment not furnished by company.

   Penstock: Diameter .....mm Material ....
   Valves:
   Electrical equipment:

   Additional items:

3. Additional services provided by the Company (i.e., financing, complete design, installations, etc.):

4. Please provide the names and addresses of three developers who have installed and operated your units.

5. Additional Comments:

4. CIVIL WORKS AND EQUIPMENT

INTRODUCTION

This section of the Small Hydro Handbook goes into considerable detail on sites, dams, intakes, penstocks, turbines, equipment, and related considerations. You are advised to skim it quickly, and then refer back to individual sections, as you plan and develop your project.

4.1 DAMS

Synopsis

This discussion is limited to dams of seven feet maximum height. Small dams vary from simple weirs which divert water into a canal or pipe, up to elaborate concrete structures which have flood gates and many other features. The size and type of dam depend to some extent upon the downstream consequences of a washout. For instance, storing sufficient water behind a six or seven foot dam could constitute a serious potential hazard to residences, railroads, and highways located downstream. The failure of such a dam could not be tolerated, and the potential hazard involved would necessitate thorough engineering and construction techniques, even though the dam itself is quite small. On the other hand, a timber or rockfill dam located in a remote creek could fail without causing any particular hazard, especially where only a small volume of water is impounded. To conclude, embarking on the construction of small dams is unwise unless the developer understands the level of potential hazard, and the basic principles of design and construction.

The design and construction of dams are anything but simple; instinct and intuition are, in this case, unreliable guides. As a hydro developer, you are again cautioned against building dams more than seven feet high without first having obtained professional guidance. This caution is given because all types of dams are vulnerable to particular kinds of failure; and failures are certain to result unless knowledge and experience are brought to bear on vital areas such as conditions for foundations, magnitude of flood water, and the structural strength of the dam. Professional geotechnical and hydrological studies are necessary for all dams above seven feet, particularly when larger streams with extensive watersheds are involved. Professional involvement may be necessary on dams less than seven feet if a washout could cause downstream damage. The final object is to achieve a sound and reliable design which is at the same time economical to construct.

There are several cases where dams (as opposed to simple intakes) may be necessary:

(a) where storage is necessary to meet daily peak loads of short duration (pondage),

(b) where storage is necessary to maintain energy production during yearly low flow periods,

(c) where a combination of the above exists, or

(d) where silt and sand loads in the stream are such that a stillage reservoir is necessary to reduce the amount of sand and silt reaching the turbine.

On very small systems, particularly those located on mountain streams, worthwhile storage is usually uneconomic to achieve. However, keeping sand out of the turbine is sufficient cause to consider the construction of a dam. Later in this section, we will describe a series of small dams suitable for construction in remote locations.

Water pressure behind the dam is commonly understood to be the only important consideration in the design of dams. This is a misreading of the facts. Water forces acting in dams up to six or seven feet (2 metres) are significant, but quite easy to cope with from a structural standpoint. The main difficulty to be dealt with is the effect of weight and hydraulic pressure on the ground below the dam, along the banks, and on the material of the dam itself. All dams are vulnerable to percolation of water through or past the dam, and all dams leak. The art is to ensure that the leakage is so small that material cannot be washed out of the dam, or out of the foundations or abutments. Moreover, the dam must be homogenous throughout each section so that leakage cannot concentrate at any one area. Spillway capacity must be sufficient to cope with the anticipated maximum run-off, plus a sizeable safety factor to allow for unusually high spring floods compounded by freak storms.

Earth and rock fill dams cannot be designed to withstand overtopping, and will quickly wash out should this occur. There are problems associated with siting spillways and culverts in earth and rock fill dams, and if it is possible to locate these away from the main dam, then by all means do so. Timber structures are liable to failure from overtopping, frequently caused by the washing away of the downstream toe and channelling around the ends. If overtopping is particularly severe, the structure may slide downstream. Concrete dams are often designed for a certain amount of overtopping, and as they are normally built on solid rock, failure is less likely. Gabion weirs, which consist of rock filled wire cages, act as gravity structures which will accommodate moderate overtopping, provided abutments and the downstream area is protected against erosion.

Spillways for Dams

If you build a dam across a stream the dam must have a free overflow spillway or sluiceway large enough to pass very large streamflows. The magnitude of these very large streamflows (called the Spillway Design Flood) depends on:

(a) the height of the dam;
(b) the amount of water behind the dam;
(c) the amount of damage that could be caused if the dam failed.

There is always the possibility that the dam could fail and cause damage to property or harm people downstream. Therefore, the spillway or sluiceway must be carefully designed. Normally, it should be designed by an engineer.

However, for certain conditions (listed below) you can use the method given here to calculate the length of the spillway. The conditions that must be met are:

(a) the dam is less than 7 feet high;
(b) the dam is located such that, if it failed, there would not be major damage to property or harm to persons downstream.

The method applies to a free overflow spillway. It assumes that the spillway must pass the maximum flow that has occurred in the stream at the location where you will build the dam. The maximum flow can be estimated from the highest water level that has occurred within the last few years. Evidence of the highest water level could be found from:

(a) the highest level at which roots of trees or bushes are exposed along the banks;

(b) the level of debris - twigs, grass, bark - found in tree roots or bushes along the banks.

To calculate the length of the free overflow spillway follow these steps:

1. Find the highest water level that has occurred in the stream during the last 3 to 5 years, longer if evidence is available.

2. Make a scaled drawing of the stream cross-section similar to the one in Figure 4.1(a). To do this:

   (a) measure the depth of the stream (from the present water level) at several points, and measure the distance of each point from one bank;
   (b) measure the distance between the present water level and the highest evidenced flood level.

3. On the stream cross-section draw a rectangle that has the same area as the area below the highest water level (eg. rectangle a b c d in Figure 4.(a)).

4. From the drawing, scale off the average depth H (equal to the height ab) and the average width W (equal to the distance ad): write down these values of H and W.

5. Calculate the slope of the river bed at the same location as the cross-section, by measuring the drop in the river bed over a measured distance; eg. a drop of 5 ft. in 50 ft. is a slope of 5/50 = 0.1 or 10%.

6. From the curves on Figure 4.(c), with the stream depth H and the slope S%, read off the value of k on the horizontal axis; eg. for H = 3, S = 5%, K = 3.7.

7. Calculate the length of the spillway from the equation:

$$L = K \times W$$

Where: L = length of free overflow spillway, in feet
K = factor from Figure 4.(c)
W = average width of stream, in feet, scaled from the cross-section.

Notes:

1. The length of spillway calculated above is for a depth of water in the reservoir 3 feet above the spillway crest. For all dams that are not designed to be overtopped eg. earth-fill or rock-fill dams, the level of the spillway must be at least 4 feet below the top of the dam (as shown in Figure 4.-(b).

2. The curves on Figure 4.1(c) are for small streams, and are valid only to the left of the dashed line. If your combination of stream depth H and slope S plots to the right of the dashed line you should not use this approximate method. An engineer should be asked to design the spillway.

Design Considerations and Common Sources of Failure

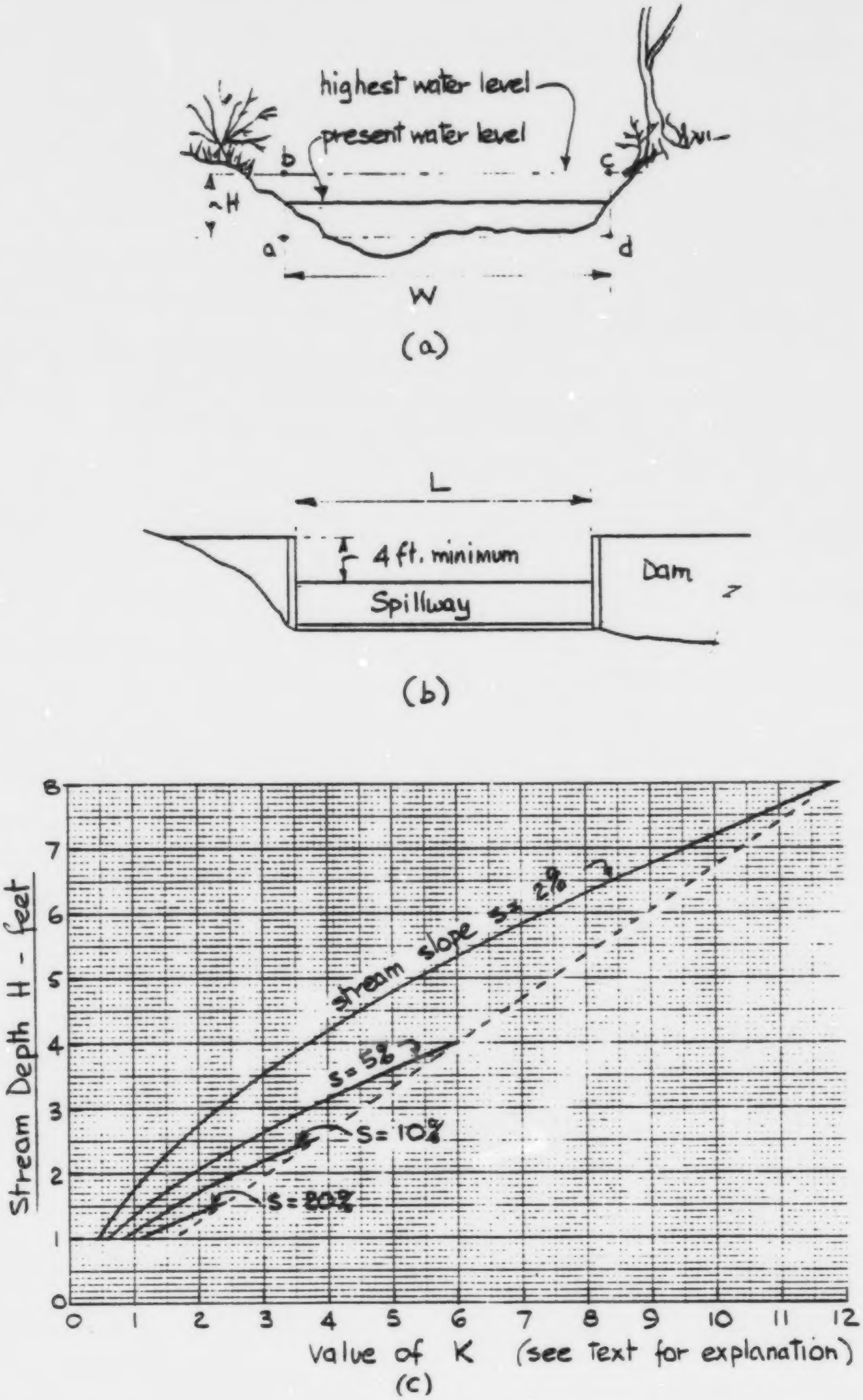
1. Failure by overtopping results when the spillway capacity is inadequate to pass flood water or high runoff. The water level rises, and eventually overflows the dam. Earth or rockfill dams will be washed away quickly by overtopping, and other types of dams can be damaged seriously.

2. Wash-out around the ends of the dam is caused by inadequate spillway capacity, or by inadequate abutments which do not project far enough into the banks. Inadequate bank protection on the upstream or downstream side can lead to excessive scouring away and slumping of the banks into the reservoir or stream.

3. Undermining caused by excessive percolation of water under the dam quickly leads to a wash-out.

4. Improper choice of aggregated and/or improper placement or inadequate compaction in earth and rock fill dams can result in failure.

5. Downward slumping of material results from too steep an angle on rock or earth fill dams. The upstream face is particularly vulnerable to the effects of saturation, drawdown, ice, and wave action. Earth fill dams should always be protected on the upstream face by a hand placed layer of flat rocks or concrete tiles, and with an additional rock berm at the toe.


highest water level
present water level
b
c
~H
a
d
W
L
4 ft. minimum
Spillway
Dam
stream slope S = 2%
S = 5%
S = 10%
S = 20%
Stream Depth H - feet
Value of K (see text for explanation)
0
1
2
3
4
5
6
7
8
9
10
11
12

(a)

(b)

(c)

FIG 4.1 FREE OVERFLOW SPILLWAY

6. Failure through enlargement of the leakage path into pipes or channels can result from leakage of water along the interface between earth fill and adjacent concrete or penstock structures. Penstocks should have welded onto them a seepage collar of at least two pipe diameters. Concrete surfaces should have a channel or projection to key the fill into the structure and increase the seepage path.

7. Collapse can result from improper design or construction of timber dams. The usual causes are: too steep an angle in the upstream face which does not provide sufficient vertical weight of water to hold the dam in place, and skimpy and inadequately morticed timbers which may buckle and slide out of position. Sleepers must be accurately slotted into deep trenches in the ground. Either rock piles or wooden spillway chutes, or both, are necessary to avoid undermining of the foundation.

8. Accelerated rotting of timber dams can occur when the timber is alternately wet and dry. Some leakage should be permitted in order to keep the timbers wet.

9. Failure of rock or earth fill dams can result from inadequate compaction of fill and the use of unsuitable material. Impervious material consisting of a naturally occurring mixture of clay and sharp grit or heavy clay soil can be rammed into a hard, durable, water resistant mass. When selecting impervious material have it checked out by an experienced contractor or a soils laboratory. Pure clay is too plastic and when saturated and subjected to hydraulic pressure, will be squeezed out. Pure clay can, however, be used for upstream impervious seals, provided it is thick enough and is protected from wasting away.

10. Downstream scour can occur where the toe of the dam or adjacent banks are washed out during high water conditions.

11. Collapse of the banks causing damage or failure through overtopping of earth or rockfill dams can result from upstream bank instabilities. The stream banks may have to be protected from slumping into the reservoir.

12. Physical deterioration can be caused by erosion, weathering of concrete, settlement, etc.

The trench excavated for the wing walls and foundations should be as narrow as possible; just wide enough for the dam, otherwise an excessive amount of backfill may be required. The backfill must be impervious, and well consolidated into all spaces and pockets.

Cut-Off Walls

Seepage under the dam can be controlled by means of a barrier wall beneath the dam. The barrier wall of an impervious wall consisting of priming planks, sheet piling, or a trench filled with impervious soil. This wall spans the distance between the bottom of the dam

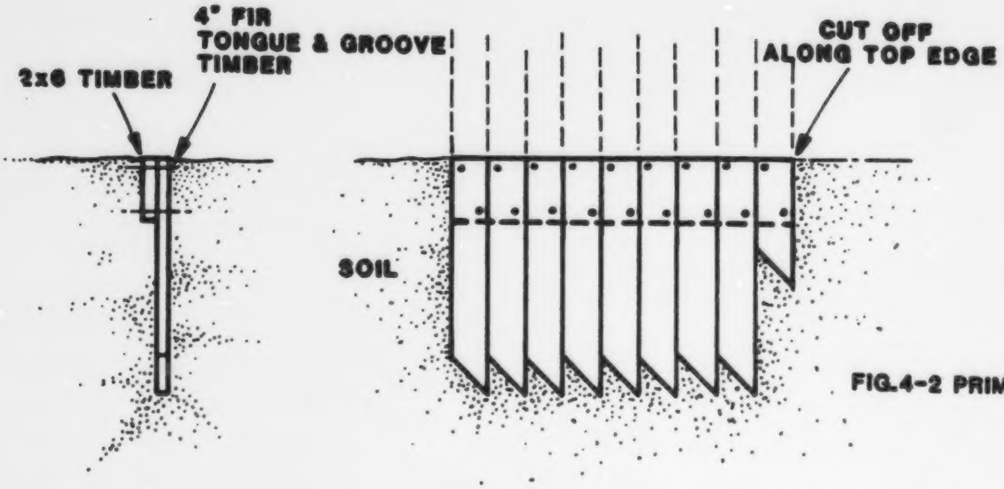
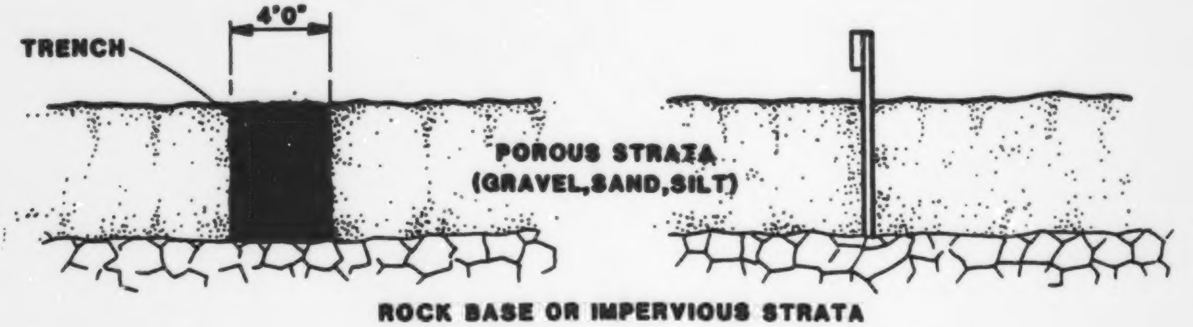

4" FIR
TONGUE & GROOVE
TIMBER
2x6 TIMBER
CUT OFF
ALONG TOP EDGE
SOIL

FIG.4-2 PRIMING PLANKS


4'0"
TRENCH
POROUS STRATA
(GRAVEL,SAND,SILT)
ROCK BASE OR IMPERVIOUS STRATA

TRENCH FILLED WITH IMPERVIOUS MATERIAL

PRIMING PLANKS OR SHEET PILING

FIG.4-3CUT-OFF TRENCH
or
DIAPHRAM

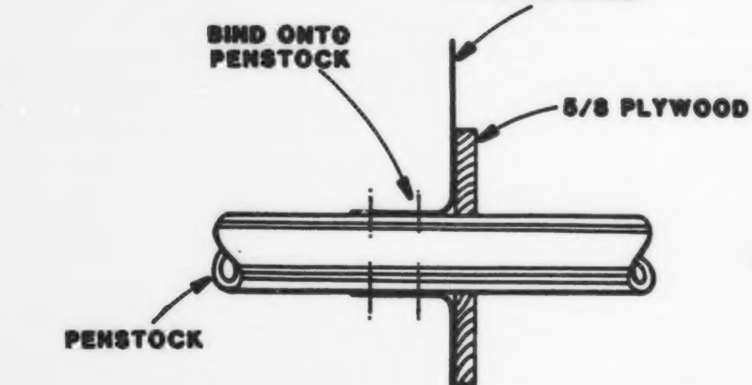

PLASTIC SHEET
BIND ONTO
PENSTOCK
5/8 PLYWOOD
PENSTOCK

FIG.4-4SEAL ON PENSTOCK

and, where possible, the natural impervious strata below the surface. In cases where impervious soil cannot be reached, the seepage distance along the base of the dam is increased by means of a sheet plastic or impervious soil layer extending upstream of the dam.

Rip stop tarpaulins or 10-mil black pvc plastic is commonly used for sealing small dams. Lay as well as possible, but fold here and there as necessary. Do not cut unless cuts can be nailed onto plywood or backing. To fit over the penstock, cut a hole smaller than the pipe and force over the end. Bind the overlap with pvc tape or fibreglass cord. Alternatively, make a close fitting hole in a sheet of 5/8" marine plywood, and nail the plastic to that. All holes and gaps, especially at the bottom of the dam, should be carefully avoided, or at least patched using plastic cement.

Priming Planks

Priming planks are a practical way of controlling seepage under the dam. They consist ideally of 4" tongue and groove planks, but 2 x 6 timbers may be used. The planks are cut off at a sharp angle so that when driven they tend to force themselves together. They should be driven as deep as reasonably possible, usually two to three feet.

Forces on Dams

The main force to be resisted is the force caused by the weight of water behind the dam.

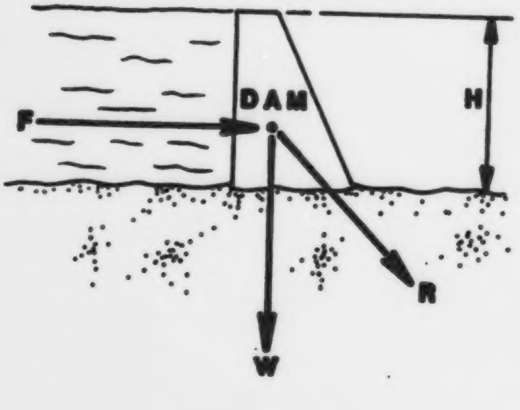


FIG.4-5FORCES ON DAMS

FORCE ON DAM PER FOOT OF LENGTH

$$F = H \times \frac{H}{2} \times 62.5$$

Examples:

- 4-ft dam, 30 ft long

$$F = 4 \times \frac{4}{2} \times 62.5 \times 30 = \underline{1500 \text{ lbs}}$$

- 7-ft dam, 30 ft long

$$F = 7 \times \frac{7}{2} \times 62.5 \times 30 = \underline{45937 \text{ lbs}}$$

- 15-ft dam, 30 ft long

$$F = 15 \times \frac{15}{2} \times 62.5 \times 30 = \underline{210{,}937 \text{ lbs}}$$

As you can see, the force of the water rapidly builds with increasing height, and this is the main reason this publication limits its discussions to dams of seven feet or less height. Up to four or five feet, especially if the dam is quite short, almost any construction that is heavy, well built, and securely tied into the soil strata will be suitable.

Practical Dams for Do-It-Yourself Construction

The possibilities for practical dams can be reduced to six basic types, with a few variations. None of these requires extensive theoretical knowledge, provided a few common basic rules are followed. The basic types are

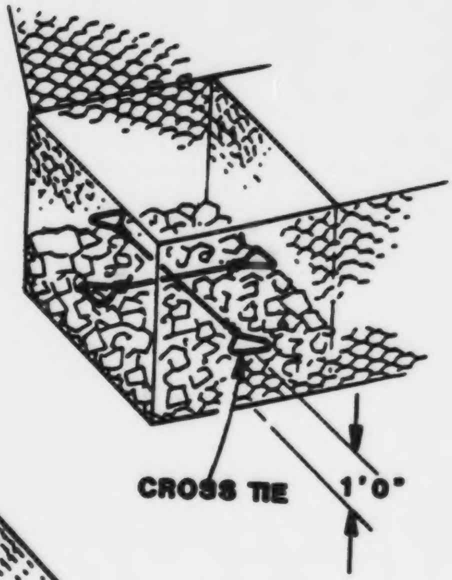
Gabions
Timber
Rockfill
Concrete
Damsack
Earth fill

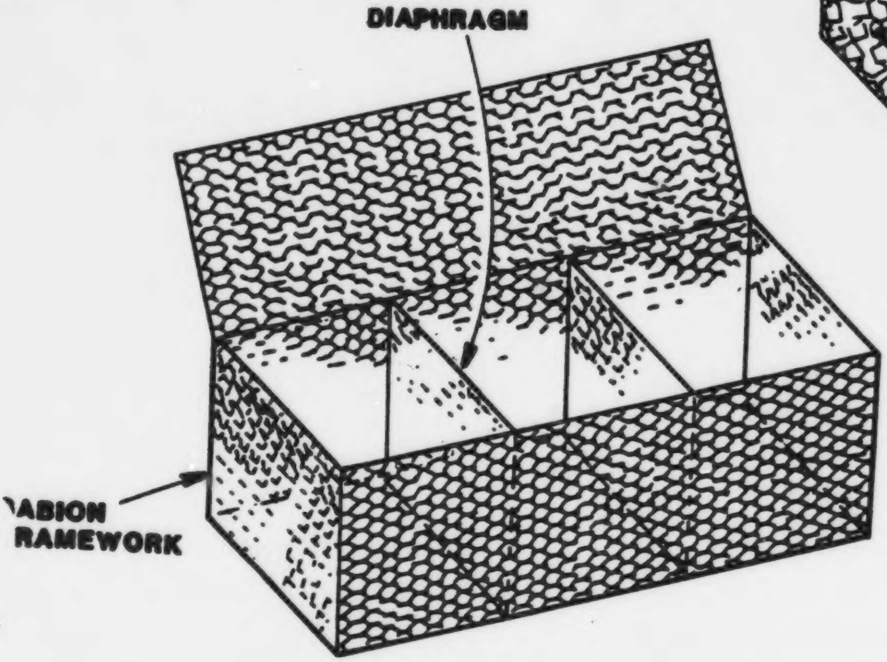
Gabion Weirs

Gabions are wire crates filled with rock (Figure 4.6) and are often used for retaining walls and weirs. They can be used to build dams in virtually any location, and are simpler and more economic than most other dams. Gabion structures will settle and adjust themselves to foundation settlement. The binding cages are made of heavy galvanized wire, which can be pvc coated for especially corrosive locations.

Gabion wiers are self-sealing to some extent as over the years the interstices between the rocks fill up with soil, leaves, and debris. For our purposes they must initially be sealed.

Gabions are compartmented rectangular containers made of heavily galvanized steel wire woven in a uniform hexagonal triple twist pattern with an opening of approximately 3x4",designed to solve the complex problems of river bank errosion and earth control.





1. For easy handling and shipping,gabions are supplied folded into a flat position.They are readily assembled by unfolding and by simply wiring the edges together and the diaphragms to the sides.
2. The gabions are filled to a depth of one foot,then one cross tie is placed in each direction and looped around tww meshes of the gabion wall.This operation is repeated until the gabion is filled.
3. Adjoining gabions are wired together by their vertical edges;empty gabions stacked on filled gabions are wired to the filled gabions at front and back.
4. After the gabion is filled the top is folded shut and wired to the ends,sides and diaphragms.

FIG.4-6GABION CONSTRUCTION

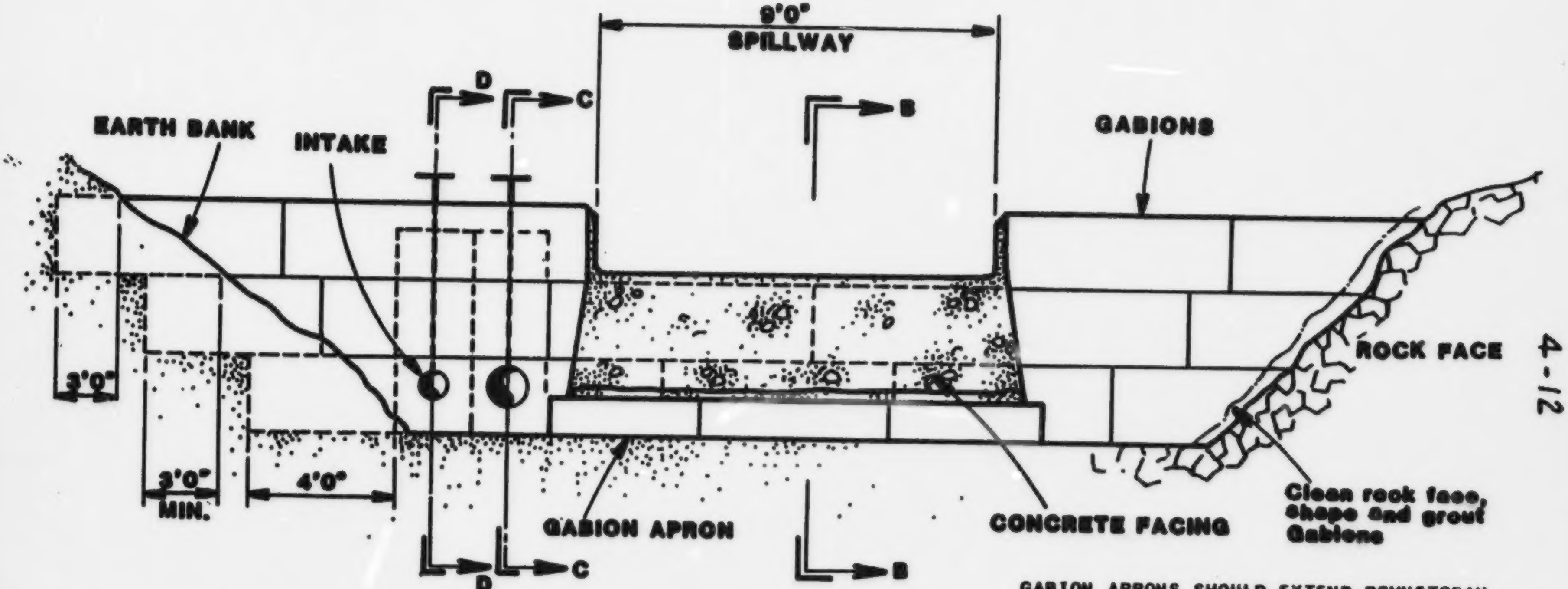
Gabion weirs can withstand torrential flow, ice, and debris, but must be sealed by, using plastic sheet, partially facing with concrete, or using an upstream fill of impervious earth. They are subject to percolation underneath the dam and along the abutments, and must be treated like earth or rockfill dams in this respect. Gabion weirs are a form of gravity dam which depends upon its weight to resist the water force acting upon it.

Facing the entire structure is not recommended since cracks developing as the dam settles may break some of the binding wires. The construction process requires that the ends of the gabion courses be excavated into the banks by at least four feet in good conditions such as clay or impervious soil; and up to six feet in pervious material such as coarse gravel or boulders. When classified banks are encountered, (sand on top, boulders on bottom layers) projection into the bank should be even greater. If in doubt get professional advice.

Where high peak run-off is normal, a downstream stilling pool should be provided to break the force of heavy spillway discharge. Run-off which results in a depth of water more than one foot over the spillway, comes into this category. A stilling pool consists of a shallow gabion weir installed at the end of the apron. For smaller discharges, a few heavy rocks should be placed to break the fall of the water. Cement grout must be placed wherever the cage wires are subjected to rapidly flowing water which will otherwise abrade the wires, allowing corrosion to start. The downstream face and apron may be protected with a three-inch layer of concrete and a four-inch layer on the spillway crest and adjacent walls. Precast concrete tiles or paving stones can be used, provided that they are securely grouted to the gabion surface. The entire surface of the gabion weir must not be grouted, so that the edges of the tiles should not be grouted.

Gabions should be carefully packed with rock. The rock used should be angular if possible, between three inches and eight inches, and carefully packed to fill the space as efficiently as possible. Wire ties are installed as the filling proceeds. The gabions tend to silt up over the years, finally self-bonding into a stable secure structure. Vegetation will eventually take hold, and the gabion will blend into the surroundings. Gabions come in a wide range of imperial and metric sizes and are shipped flat. When full of rocks, gabions are very heavy. A 3' x 3' x 12' gabion will weigh 5 1/2 tons.

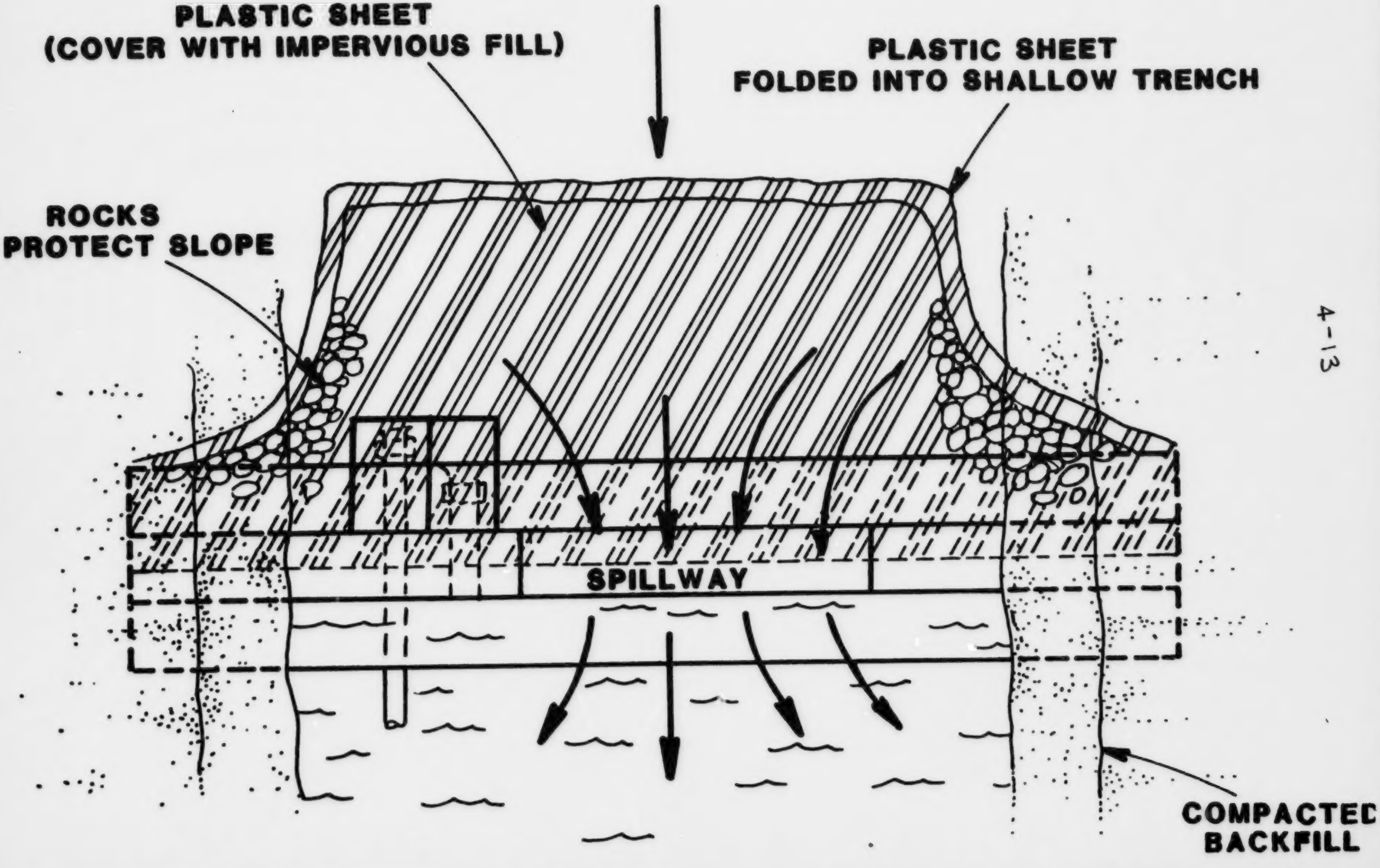
Intake pipes or clean-outs in the weir should be wired and grouted into place. The plastic seal around the intake should be cut to fit the pipe and the joint sealed with mastic or imbedded in concrete. It is usually more convenient when using gabions to form up a concrete intake box at the upstream side. Gate or slide valves can be installed in it, and a trash rack built into the front face. Construct a timber platform over the intake to give safe access.


9'0"
SPILLWAY
D
C
B
EARTH BANK
INTAKE
GABIONS
ROCK FACE
3'0"
3'0"
MIN.
4'0"
GABION APRON
CONCRETE FACING
Clean rock face, shape and grout Gabions
D
C
B

GABION APRONS SHOULD EXTEND DOWNSTREAM
IN GRAVEL:6'0"
IN COARSE SAND:9'0"
IN FINE SAND & SILT:12'0'
IN CLAY:9'0"

FIG.4-7A SMALL GABION DAM(ELEVATION)

4-13


PLASTIC SHEET
(COVER WITH IMPERVIOUS FILL)
PLASTIC SHEET
FOLDED INTO SHALLOW TRENCH
ROCKS
PROTECT SLOPE
SPILLWAY
COMPACTED
BACKFILL

DOWNSTREAM

FIG.4-7C
GABION DAM CONSTRUCTION
(SECTION B-B)

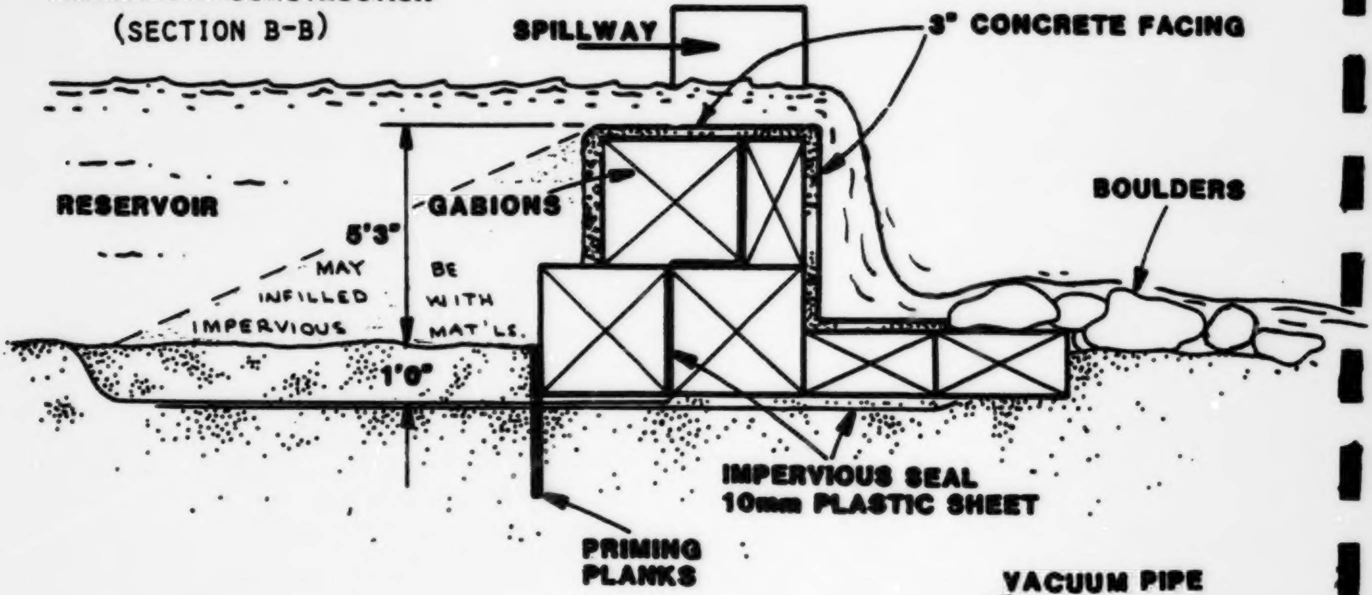

SPILLWAY
3" CONCRETE FACING
RESERVOIR
GABIONS
5'3"
MAY BE INFILLED WITH IMPERVIOUS MAT'LS.
BOULDERS
1'0"
IMPERVIOUS SEAL
10mm PLASTIC SHEET
PRIMING PLANKS

FIG4-7D
GABION DAM INTAKE
(SECTION D-D)

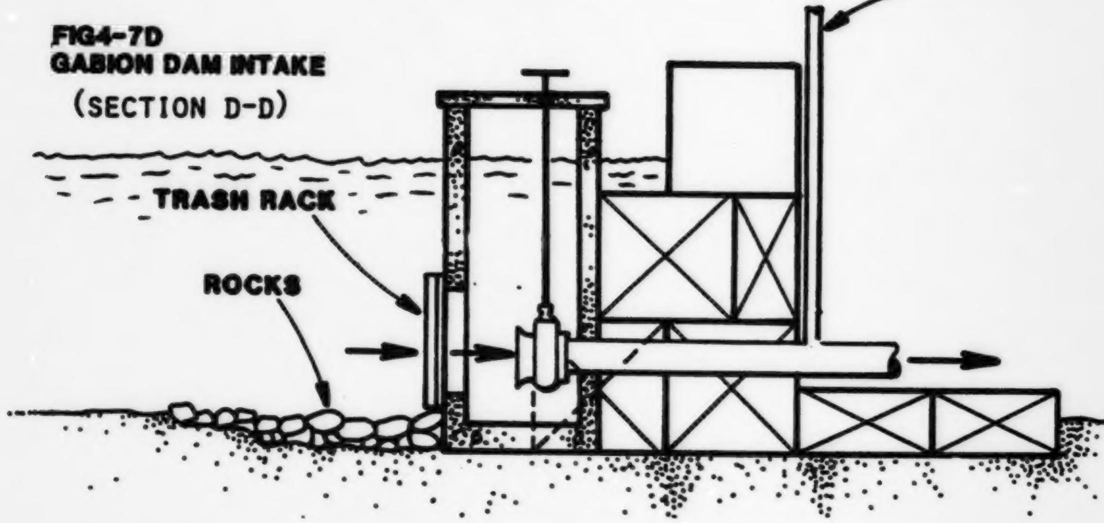
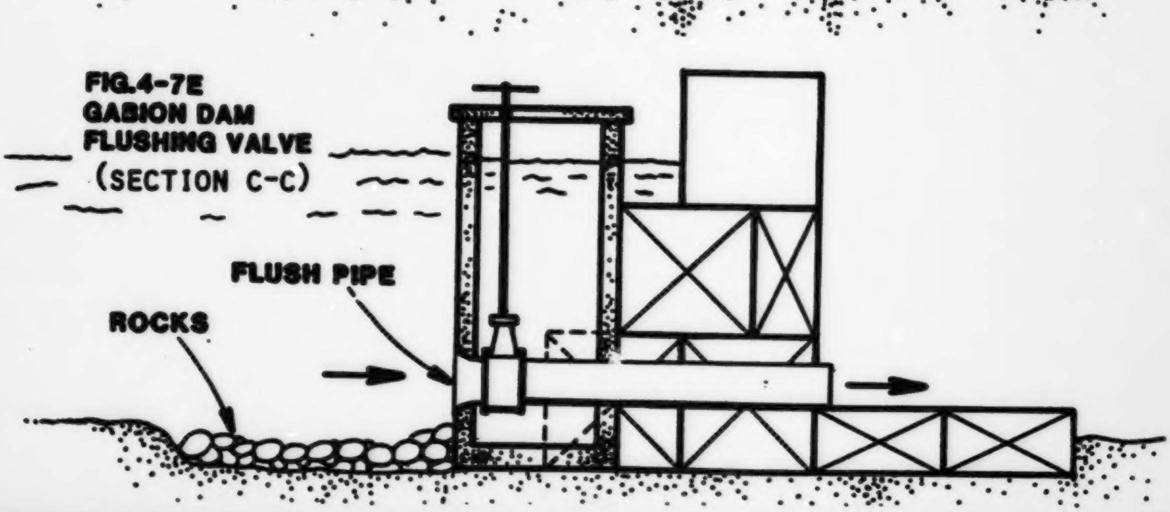

VACUUM PIPE
TRASH RACK
ROCKS

FIG.4-7E
GABION DAM
FLUSHING VALVE
(SECTION C-C)


FLUSH PIPE
ROCKS

Construct vertical seals with 1/2" or 5/8" plywood, treated with preservative, with 10-mil plastic tucked or stapled onto the upstream face. Do not use plywood on the horizontal seals.

Timber Dams

The principal feature which makes timber dams attractive for amateur construction is the fact that water discharges over the top, so that elaborate spillways are not required. The construction techniques are quite simple, but consume a lot of timber.

Timber dams should not be used where the flood discharge results in a depth of more than 12 inches of water over the spillway.

Timber dams consist of a series of self-stable triangulated frames supporting a diaphragm wall. They use the weight of water to hold themselves in place, and for that reason, the upstream face should be made gradual, say 2.5:1. Intakes and clean out valves can be built using timber.

Timber Dam on Soft Foundation

To build a timber dam on soft foundation, set sleeper logs crosswise. The upstream side must be sealed using plastic sheet. Similarly, leakage under the dam must be controlled by means of priming planks or an upstream plastic sheet seal. (See Fig. 4.8 and 4.9.)

Proceed as follows:

1. Set sleepers full depth into trenches, at least 14 to 18 inches.
2. Mortice all log joints and spike together.
3. Install 10 mil plastic seal between timber layers and fold into the cut-off trench.
4. Ensure that the cut-off trench reaches into impervious material, otherwise use priming planks.
5. If a cut-off wall cannot be used, extend the plastic sheeting upstream about 12 feet and cover with impervious fill to a depth of one foot. Slope fill to a third the height of the timber facing and protect it with rocks.
6. Fill the downstream side of the dam with rocks at least half full, and make a pile of heavy rocks to break the force of the spillway.
7. Carry the structure, including the plastic diaphragm, at least four feet or more into the banks (see "Design Considerations").
8. Build vertical extensions or wing walls at each end to prevent cutting of the banks.

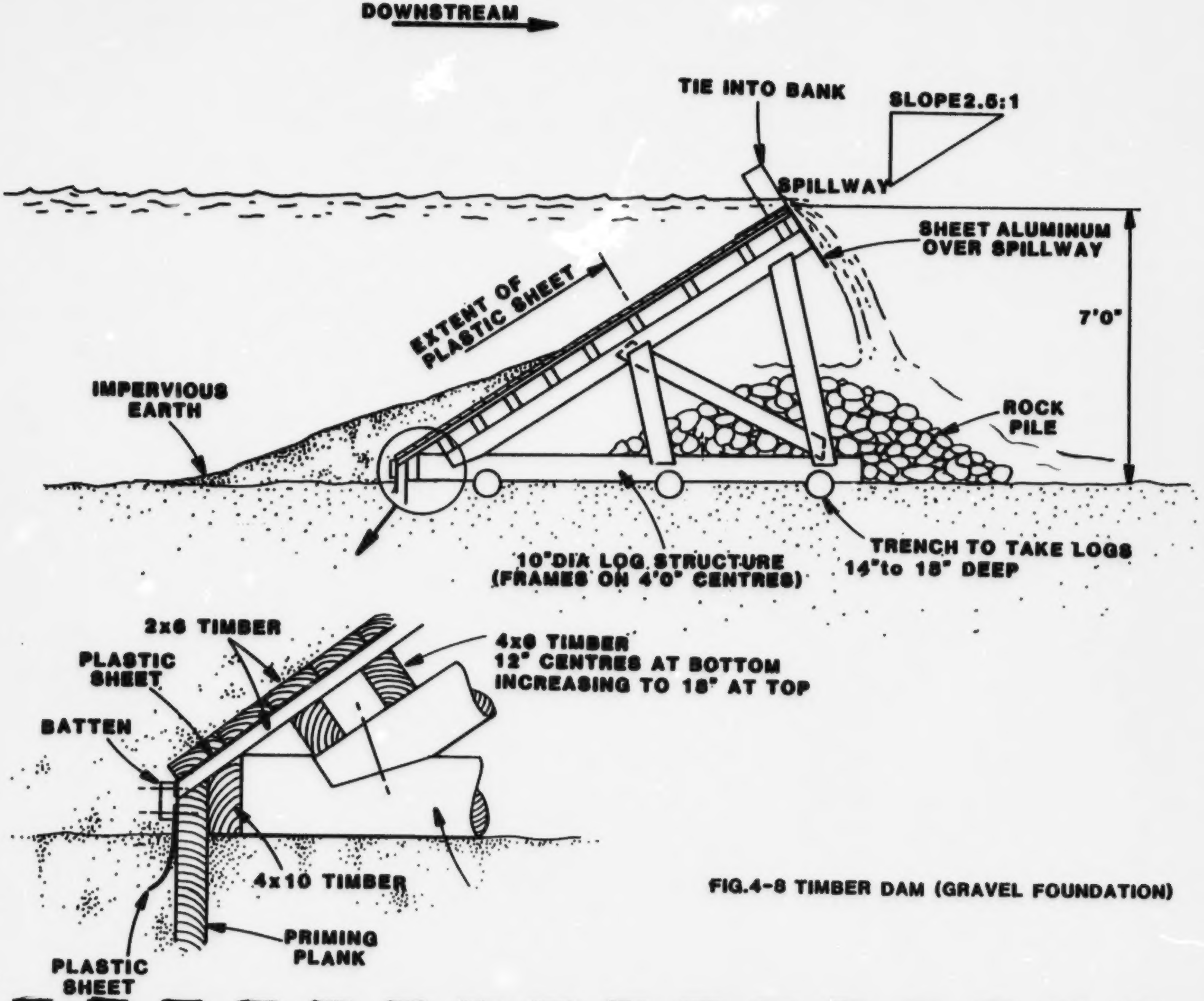

DOWNSTREAM
TIE INTO BANK
SLOPE2.5:1
SPILLWAY
SHEET ALUMINUM OVER SPILLWAY
7'0"
EXTENT OF PLASTIC SHEET
IMPERVIOUS EARTH
ROCK PILE
10"DIA LOG STRUCTURE (FRAMES ON 4'0" CENTRES)
TRENCH TO TAKE LOGS 14"to 18" DEEP
2x6 TIMBER
PLASTIC SHEET
BATTEN
4x6 TIMBER 12" CENTRES AT BOTTOM INCREASING TO 18" AT TOP
4x10 TIMBER
PRIMING PLANK
PLASTIC SHEET

FIG.4-8 TIMBER DAM (GRAVEL FOUNDATION)

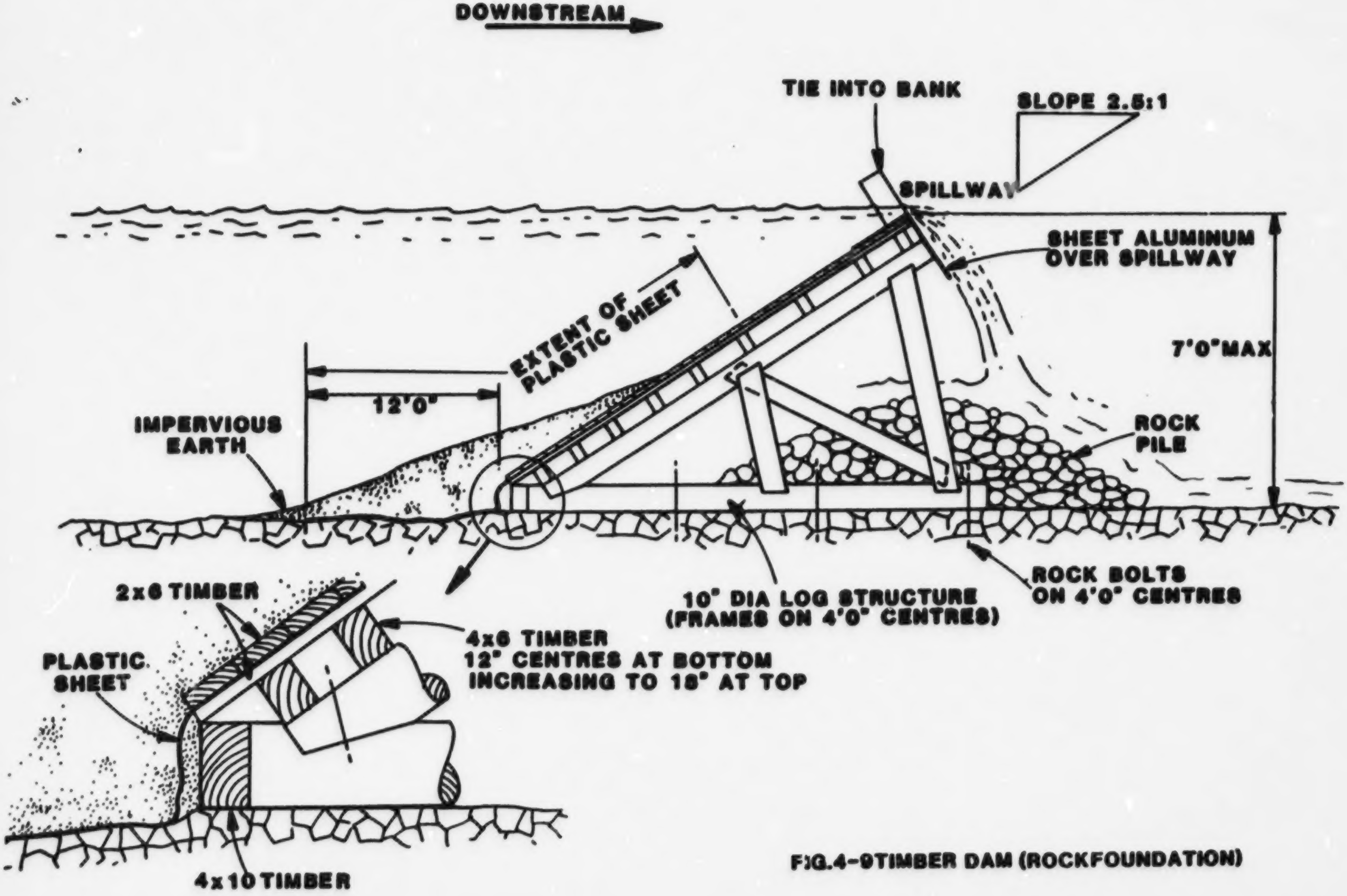

DOWNSTREAM
TIE INTO BANK
SLOPE 2.5:1
SPILLWAY
SHEET ALUMINUM OVER SPILLWAY
EXTENT OF PLASTIC SHEET
7'0"MAX
12'0"
IMPERVIOUS EARTH
ROCK PILE
ROCK BOLTS ON 4'0" CENTRES
10" DIA LOG STRUCTURE (FRAMES ON 4'0" CENTRES)
2x6 TIMBER
4x6 TIMBER 12" CENTRES AT BOTTOM INCREASING TO 18" AT TOP
PLASTIC SHEET
4x10 TIMBER

FIG.4-9TIMBER DAM (ROCKFOUNDATION)

Timber Dam Set on Rock

The dam is built of 10" to 12" logs or timbers, all morticed and spiked together. The ends of the dam must be cut into the banks at each side with a layer of plastic sheeting over the timber where in contact with earth. When butted against rock, the gaps between the timber and rock can be grouted. Each sill log should be rock bolted on four foot centres. Jack hammer or rock drill 1-1/2" holes about 3' deep and grout the bolts into place. Build a rock pile inside the dam to increase resistance to sliding and to dissipate the force of water coming over the dam.

Timber Crib Dams

Timber crib dams are built of a latticework of logs or timbers filled with rock. The timbers are spiked together and filled with rock as construction proceeds. These structures gradually silt up and are self-sealing. Since these dams use a great deal of timber, you should evaluate the cash value of the logs against other types of construction such as gabion wiers or rock fill dams.

Rock Fill Dams

Rock fill dams are built of rock fill with a central core of impervious fill. The rock fill section consists of quarry rock or talus slope rock which is hard, angular, and durable. Do not use well-rounded rock which will gradually slide; choose instead rough and angular rock which will key together. Avoid shale and sandstone which will weather quickly and break-up, and avoid fines, consisting of dirt, sand, and clay, in rock fills: the more fines, the more settlement. Clean solid rock is necessary.

A rock fill dam is constructed as follows:

1. Clean the site, removing vegetation and soil containing organic material. Excavate into the stream shoulders for a depth necessary to secure an adequate seal (see "Design Considerations").

2. Install a cut-off trench or priming planks. The cut-off trench should reach into impervious strata or down to bedrock, and priming planks must be driven as deeply as possible.

3. The impervious material should consist of clay type soils. See Figure 4-11 for a classification of soils and core material for earth fill dams.

4. Build the dam up in layers about 12" thick and then compact the layers. Rockfill dams will settle excessively unless carefully compacted during construction.

5. Install the penstock and flush pipe as the dam is built up. Be sure to weld on a leakage collar about two pipe diameters at a place where the pipe will be buried in the impervious section.

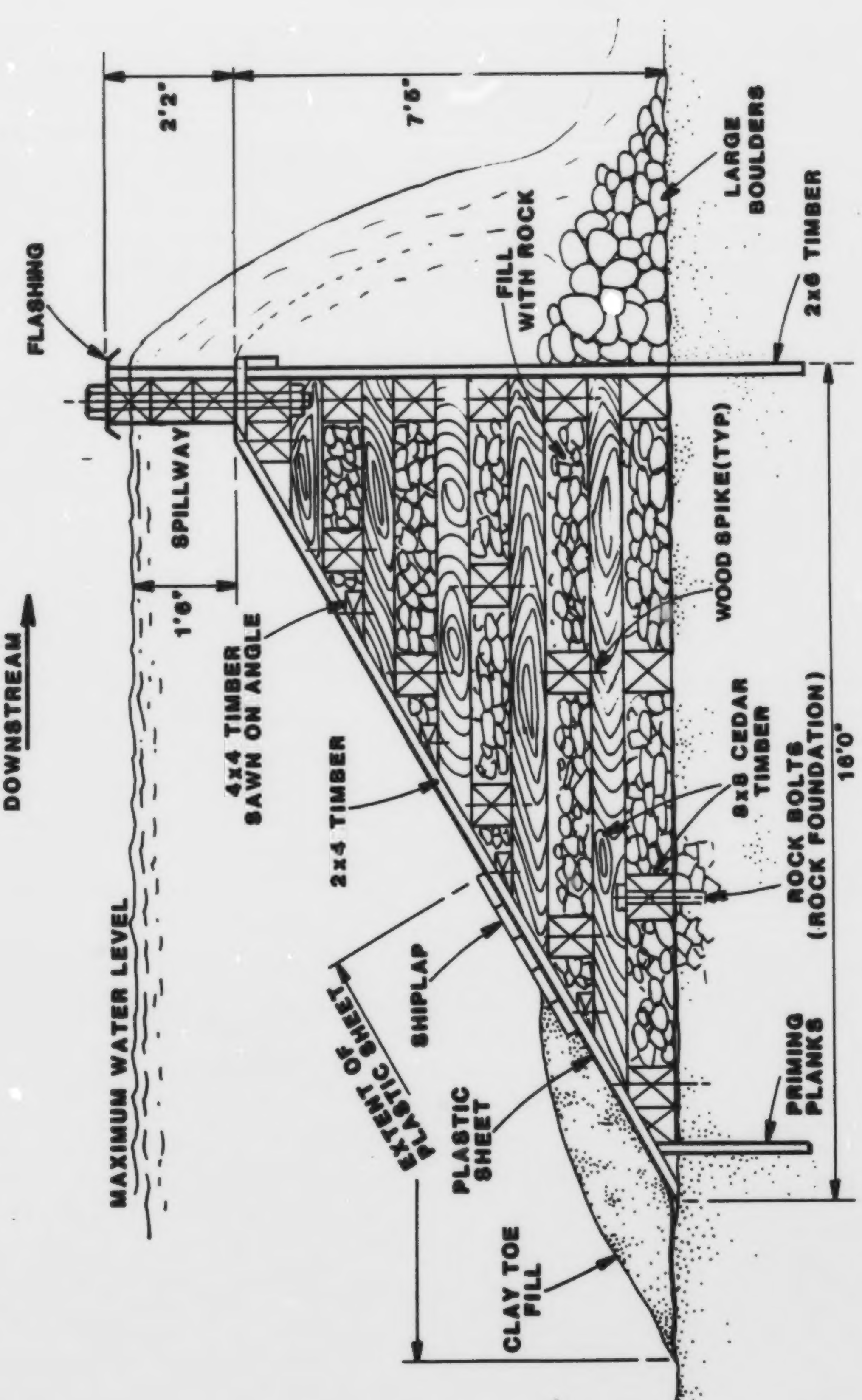

DOWNSTREAM
MAXIMUM WATER LEVEL
FLASHING
2'2"
7'5"
SPILLWAY
1'6"
4x4 TIMBER SAWN ON ANGLE
2x4 TIMBER
FILL WITH ROCK
LARGE BOULDERS
2x6 TIMBER
WOOD SPIKE(TYP)
8x8 CEDAR TIMBER
ROCK BOLTS (ROCK FOUNDATION)
SHIPLAP
EXTENT OF PLASTIC SHEET
PLASTIC SHEET
CLAY TOE FILL
PRIMING PLANKS
16'0"

FIG.4-10 CRIB & DECK DAM

Description of Soils

	Field inspection procedures	Group symbol	Typical names
Coarse grained soils			
Gravels: Clean	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
With fines	Nonplastic fines (for identification procedures see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures
	Plastic fines (for identification procedures see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
Sands: Clean	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	SW	Well-graded sands, gravelly sands, little or no fines
	Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines
With fines	Nonplastic fines (for identification procedures see ML below)	SM	Silty sands, poorly graded sand-silt mixtures
→	Plastic fines (for identification procedures see CL below	SC	Clayey sands, poorly graded sand-clay mixtures

Fine grained soils

Soil type	Dry strength	Dilatancy	Toughness	Group symbol	Typical names
Silts and clays	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity
→	Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, clays
	Slight to medium	Slow	Slight	OL	Organic silts and organic silt clays of low plasticity
	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
→	High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays
	Medium to high	None to very Slow	Slight to medium	OH	Organic clays of medium to high plasticity
Highly organic soils	Readily identified by color, odor, spongy feel and frequently by fibrous texture			Pt	Pe [illegible] other highly organic soils

Recommended Slopes for Small Earth Dams on Stable Foundations

A. Zoned earthfill dams

Type	Purpose	Subject to rapid drawdown*	Shell material classification	Core material classification†	Upstream slope	Down-stream slope
Zoned with "minimum core"‡	Any	Not critical	Rockfill, GW, GP, SW (gravelly), or SP (gravelly)	GC, GM, SC, SM, CL, ML, CH, or MH	2:1	2:1
Zoned with "maximum core"‡	Detention or storage	No	Rockfill, GW, GP, SW (gravelly), or SP (gravelly)	GC, GM SC, SM CL, ML CH, MH	2:1 2½:1 2½:1 3:1	2:1 2½:1 2½:1 3:1
Zoned with "maximum core"‡	Storage	Yes	Rockfill, GW, GP, SW (gravelly), or SP (gravelly)	GC, GM SC, SM CL, ML CH, MH	2½:1 2½:1 3:1 3½:1	2:1 2½:1 2½:1 3:1

B. Homogeneous earthfill dams

Type	Purpose	Subject to rapid drawdown*	Soil classification†	Upstream slope	Downstream slope
Homogeneous or modified-homogeneous	Detention or storage	No	GW, GP, SW, SP GC, GM, SC, SM CL, ML CH, MH	‡ 2½:1 3:1 2½:1	‡ 2:1 2½:1 2½:1
Modified-homogeneous	Storage	Yes	GW, GP, SW, SP GC, GM, SC, SM CL, ML CH, MH	‡ 3:1 3½:1 4:1	‡ 2:1 2½:1 2½:1

FIG 4-11
SOILS DESCRIPTION

USE TYPE
SC
CL
CH
CLAY SOILS
TO SEAL DAMS

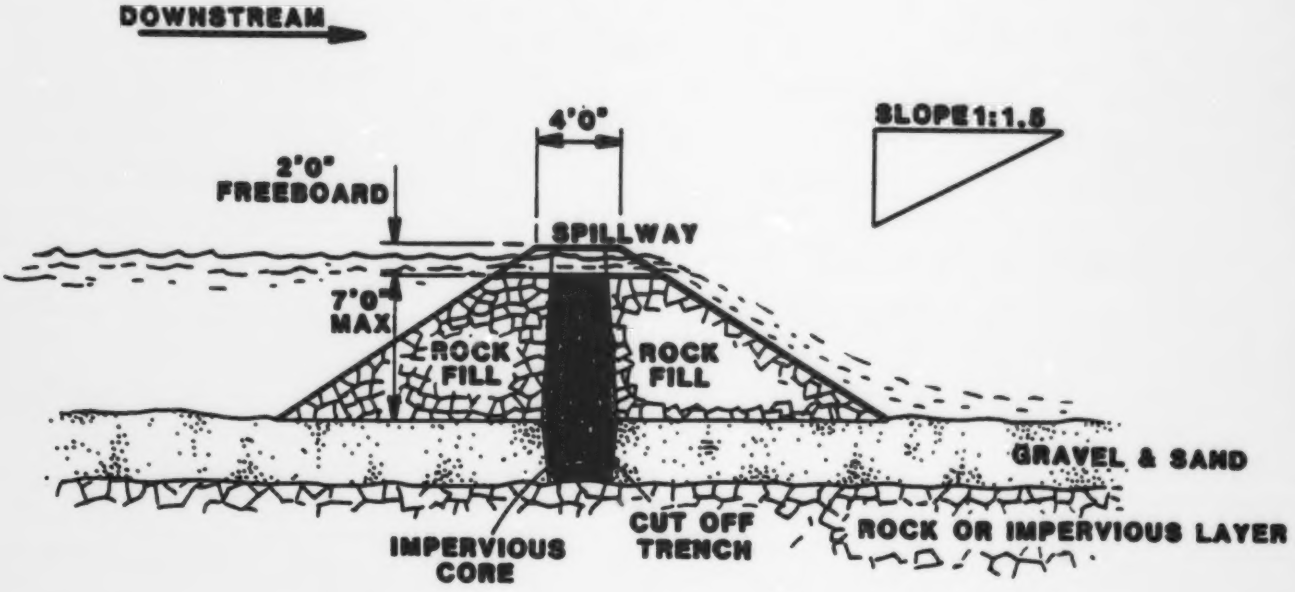

DOWNSTREAM
4'0"
SLOPE 1:1.5
2'0"
FREEBOARD
SPILLWAY
7'0"
MAX
ROCK
FILL
ROCK
FILL
GRAVEL & SAND
CUT OFF
TRENCH
ROCK OR IMPERVIOUS LAYER
IMPERVIOUS
CORE

FIG.4-12ROCK FILL DAM

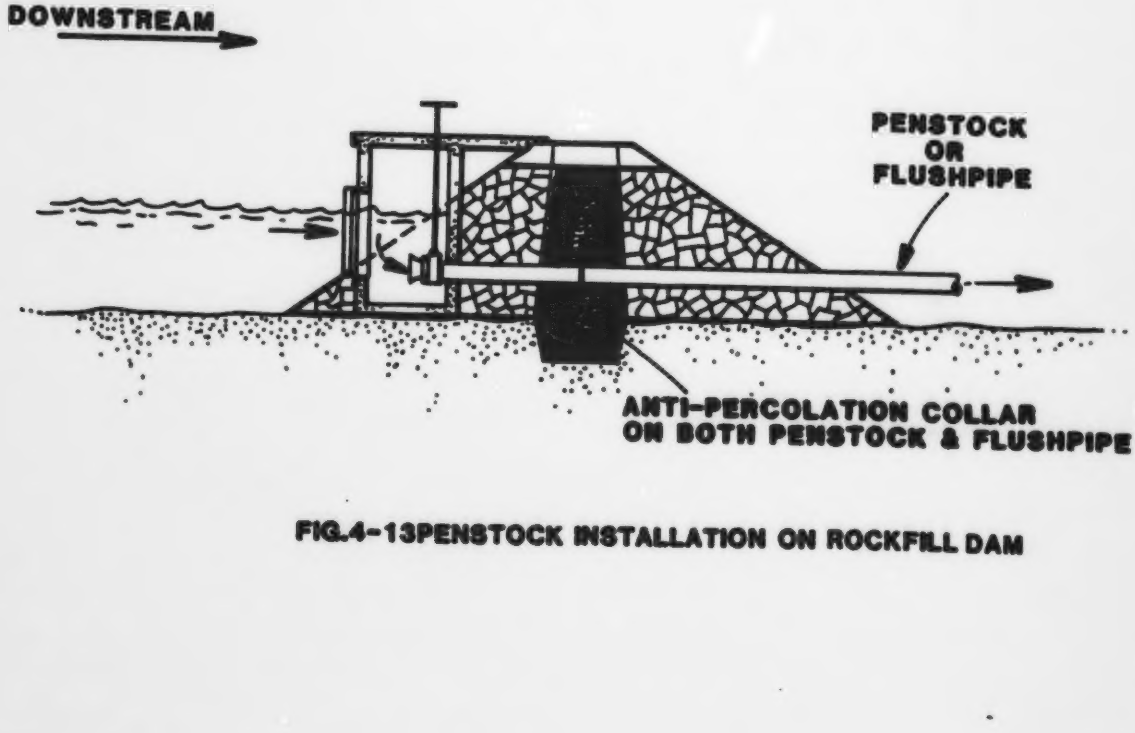

DOWNSTREAM
PENSTOCK
OR
FLUSHPIPE
ANTI-PERCOLATION COLLAR
ON BOTH PENSTOCK & FLUSHPIPE

FIG.4-13PENSTOCK INSTALLATION ON ROCKFILL DAM

Concrete Dams

Concrete dams can be used for small intakes, or for dams which will be overtopped during heavy run-off conditions. The site must be accessible to ready mix concrete, or nearby an abundant supply of good quality aggregate. Concrete dams should be considered where security and reliability are paramount. In general, concrete dams are expensive which limits their application to larger schemes.

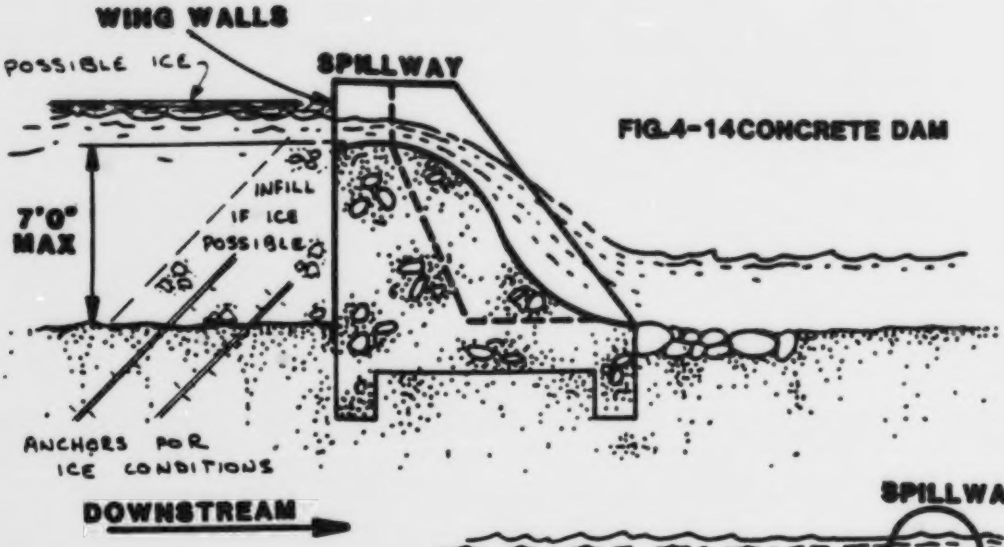

WING WALLS
POSSIBLE ICE
SPILLWAY
7'0" MAX
INFILL IF ICE POSSIBLE
ANCHORS FOR ICE CONDITIONS
DOWNSTREAM

FIG.4-14CONCRETE DAM

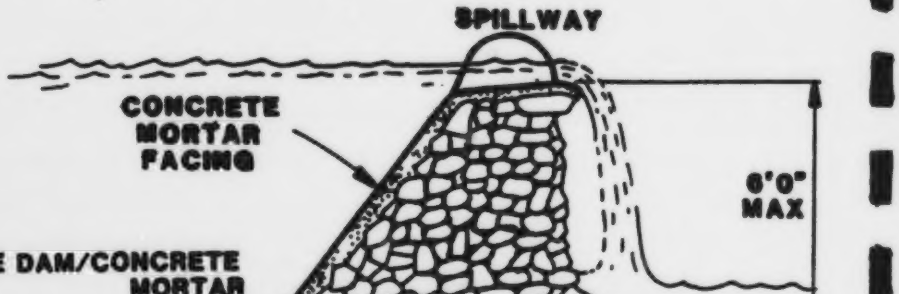

SPILLWAY
CONCRETE MORTAR FACING
6'0" MAX
IMPERVIOUS LAYER

FIG.4-15STONE DAM/CONCRETE MORTAR

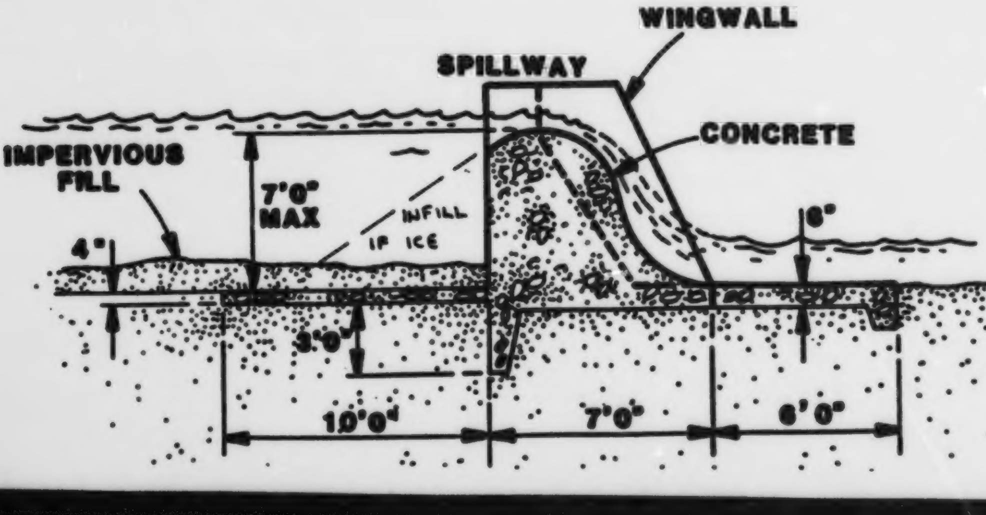

WINGWALL
SPILLWAY
CONCRETE
IMPERVIOUS FILL
7'0" MAX
INFILL IF ICE
4"
6"
3'0"
10'0"
7'0"
6'0"

FIG.4-16

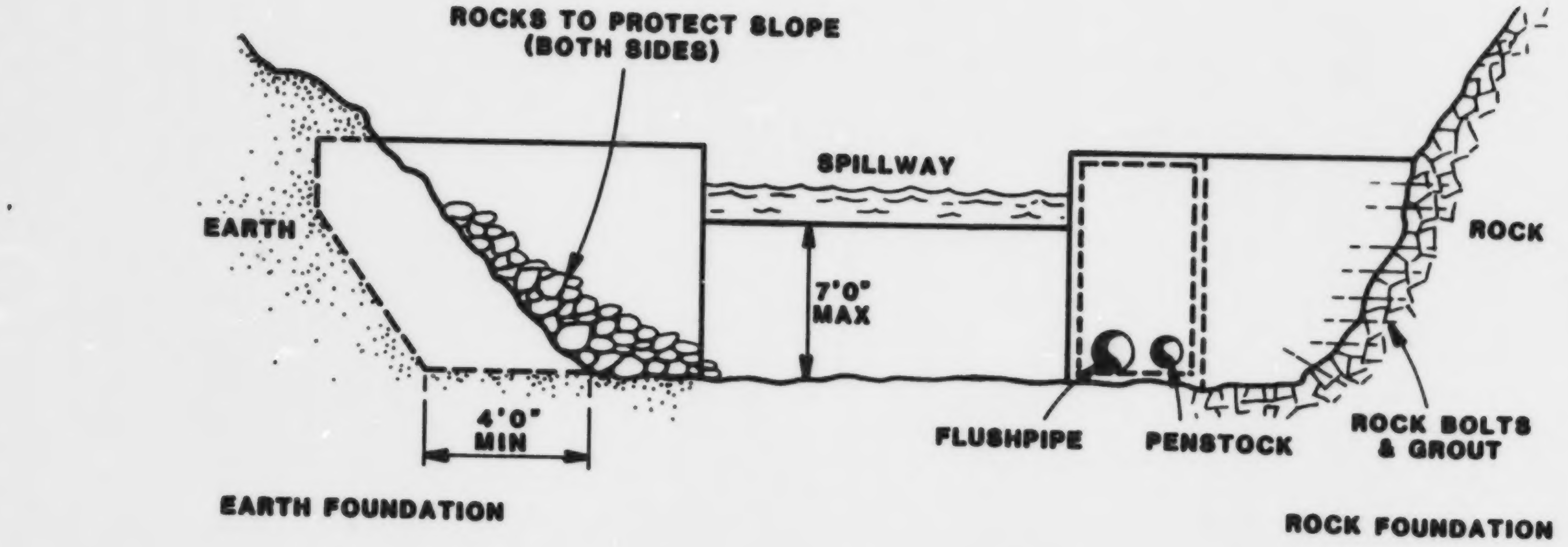

ROCKS TO PROTECT SLOPE
(BOTH SIDES)
SPILLWAY
EARTH
7'0"
MAX
ROCK
4'0"
MIN
FLUSHPIPE
PENSTOCK
ROCK BOLTS
& GROUT
EARTH FOUNDATION
ROCK FOUNDATION

FIG.4-17SMALL CONCRETE DAM(ELEVATION)

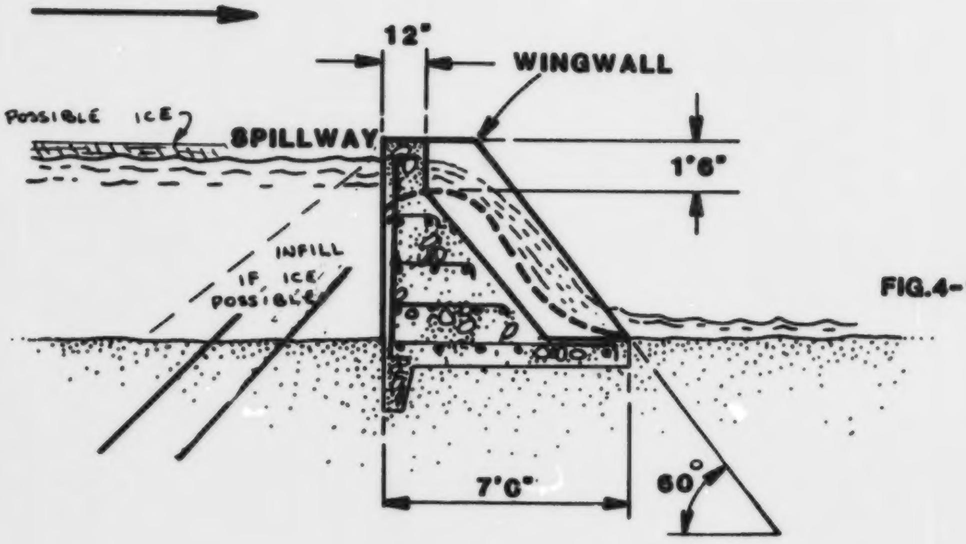

12"
WINGWALL
POSSIBLE ICE
SPILLWAY
1'6"
INFILL
IF ICE
POSSIBLE
7'0"
60°

FIG.4-18SMALL CONCRETE DAM
(BULKHEAD SECTION)

NOTE 1
A SHALLOW CUT OFF TRENCH IS REQUIRED WHEN PLACING ON ROCK FOUNDATION. THIS TRENCH IS FILLED WITH CONCRETE.

NOTE 2
ALL CONCRETE DAMS MUST BE REINFORCED USING BOTH LENGTHWISE & CROSSWISE REBARS.

TYPICAL: No.6 BARS LENGTHWISE ON 12" CENTRES
No.4 BARS CROSSWISE ON 12" CENTRES
ALL BARS MUST BE 3" BELOW LEVEL OF CONCRETE.

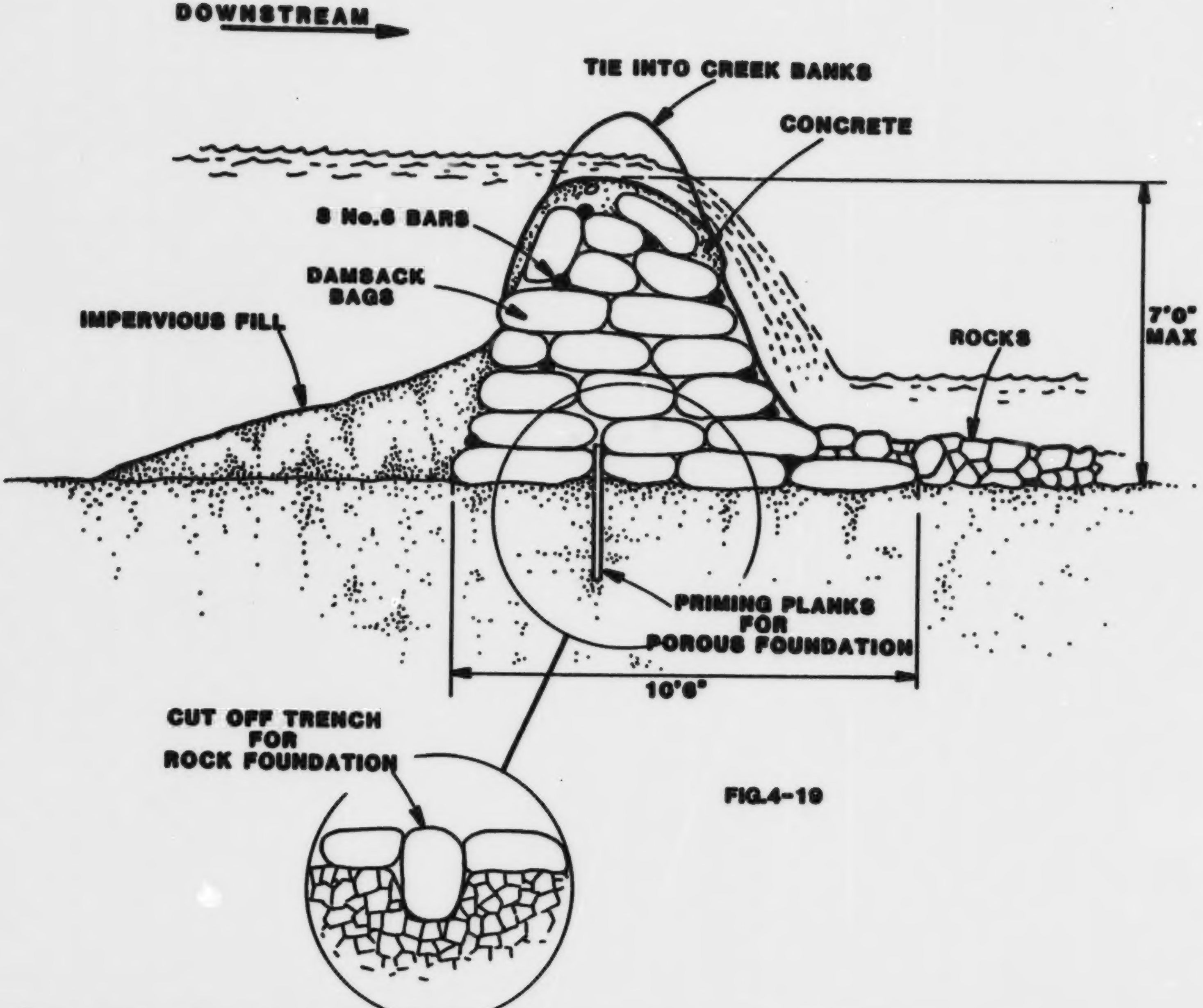

DOWNSTREAM
TIE INTO CREEK BANKS
CONCRETE
8 No.6 BARS
DAMSACK BAGS
IMPERVIOUS FILL
ROCKS
7'0" MAX
PRIMING PLANKS FOR POROUS FOUNDATION
10'6"
CUT OFF TRENCH FOR ROCK FOUNDATION

FIG.4-19

Damsack Dams

'Damsack' consists of dry mixed concrete placed in special bags. The bags are placed in position and saturated with water as the construction proceeds. The bags, which are designed to rot out quickly, are obtainable from most building material suppliers.

A damsack dam is built as follows:

1. Build up the damsack, and install No. 4 rebars longitudinally during construction.
2. Tie into rock walls by drilling six to eight holes at each end and driving in large steel rebars.
3. Grout over the top and downstream face with concrete.
4. Round the spillway section as shown, into an ogee curve, as this provides a higher rate of discharge than other shapes.
5. Construct the dam at footing level to a thickness equivalent to the total height of water at normal flow.
6. Maintain the cross-section as shown, since the weight is necessary to hold the dam in place.

Earth Fill Dams

Earth fill dams consist of three sections, each composed of different kinds of material.

The components are:

1. The cut-off trench, which reaches into impervious sub-strata. Sheet piling, concrete walls, or priming planks are often used instead.
2. The impervious material, which consists of a natural mixture of clay and sharp grit. Have this material checked out by a soils laboratory (see Figure 4-11 for soils description).
3. The rock pile, which is built-up, at the upstream toe to prevent slumping.

To construct an earth fill dam, proceed as follows:

1. Build up the dam in layers about 12" thick and compact each layer.
2. Clean off all loose material before starting on the dam. Excavate the stream shoulders to determine the necessary depth for sealing. (See "Design Considerations").

3. Install the penstock and flush pipe as the dam is built up. Be sure to weld on leakage collars of two pipe diameters or so at a place where the pipe will be buried in the impervious section.

4. Cover the upstream face with hand placed slabs of rock or concrete tiles. This protects the surface from the effects of drawing down, ice, and wave action.

5. Place the inlet structure upstream of the toe, or incorporate it in the spillway.

6. Install a concrete spillway in one of the banks, because an earth fill dam will not accept overtopping.

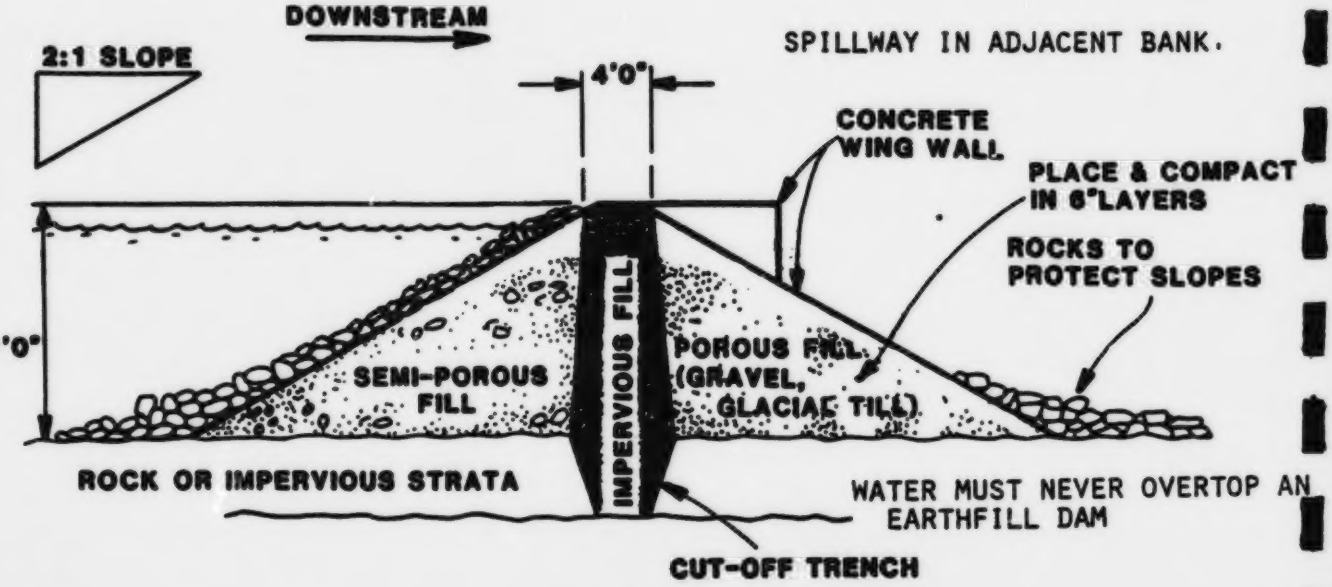

DOWNSTREAM
2:1 SLOPE
4'0"
SPILLWAY IN ADJACENT BANK.
CONCRETE WING WALL
PLACE & COMPACT IN 6" LAYERS
ROCKS TO PROTECT SLOPES
7'0"
SEMI-POROUS FILL
IMPERVIOUS FILL
POROUS FILL (GRAVEL, GLACIAL TILL)
ROCK OR IMPERVIOUS STRATA
WATER MUST NEVER OVERTOP AN EARTHFILL DAM
CUT-OFF TRENCH

FIG.4-20 SMALL EARTH FILL DAM

Note: "Earth fill" is a misnomer. What is actually used is glacial till, gravel, clayey sand and other carefully selected materials. Top soil or loose unclassified material containing humus or vegetable matter is useless. The crest and downstream areas should be covered with sod or seeded with durable grasses to prevent erosion by rainfall and wind. Top soil can be used to cover the top and downstream to add ballast weight, and to aid in the growth of vegetation which helps to prevent erosion by wind and rainfall.

Dikes and Canals

Dikes and canals can be built using earth dam principles, but are often completely built of impervious material. Canals can be lined with impervious soils to reduce leakage.

4.2 INTAKE STRUCTURES

Simple intakes can occasionally be used on slow moving streams, or at lakes or ponds where ice is not severe. Usually, however, some sort of dam is required. Most of the intakes in this section can be used without dams where conditions permit.

Intakes constitute a water conditioning and control system which can be broken down into a number of functions:

(a) to direct water into the penstock;

(b) to remove debris which may damage the turbine;

(c) to control the flow of water using valves or gates;

(d) to locate the point of water intake so that it is neither too close to the surface nor too close to the bottom.

(e) where frazil ice or surface ice is encountered, to prevent these conditions from affecting the supply of water to the penstock (see Section 9);

(f) to serve as a location for water level monitoring equipment.

All of the above functions must be integrated into the overall design, which will vary according to local conditions, plant size, and intake use, for penstock or canal.

Penstock Intakes

Penstock intakes generally consist of a box structure containing trash racks and a valve or gate. Penstocks less than 15 inches diameter usually will utilize gate valves, whilst larger ones will use some form of sliding gate. The level of the penstock is important. If it is too close to the surface, air and frazil ice can be drawn into the penstock, but if it is too close to the bottom, silt and sand may be drawn in.

Sizeable debris or gravel can jam turbine valves and can cause major turbine damage. Sand, silt, and frazil ice will sandblast the turbine valves and runner, and if allowed to persist can wear out turbine parts surprisingly quickly. Remember that the bottom level will rise as debris accumulates, and periodic flushing and cleaning will be necessary.

The penstock should be at least two penstock diameters below the water surface and at least 1-1/2 diameters above the bottom of the reservoir. Where frazil or surface ice is involved, the penstock level should be two pipe diameters below the normal ice level. This requirement, common in northern areas, usually necessitates considerable depth of water, which affect the size of dam and choice of construction. See Chapter Nine for discussion on frazil ice and cold climate requirements.

The bottom silt level will gradually increase, especially during run-off, and for this reason some form of clean-out should be built into the dam. The clean-out should be at the low point, and should consist of a pipe at least as large as the penstock and fitted with a valve. On dams where the valve is liable to freeze, the valve should be on the upstream end where it can be supported by the intake structure. Small dams can also be designed with a sliding gate arrangement.

Small reservoirs can be cleaned with a portable gold dredge pump. When cleaning the reservoir, the penstock must be shut off, and must be flushed out by means of the turbine bypass valve prior to starting up again. When cleaning the reservoir, precautions must be taken not to disturb the impervious seal, where one is used.

Nitrogen Supersaturation

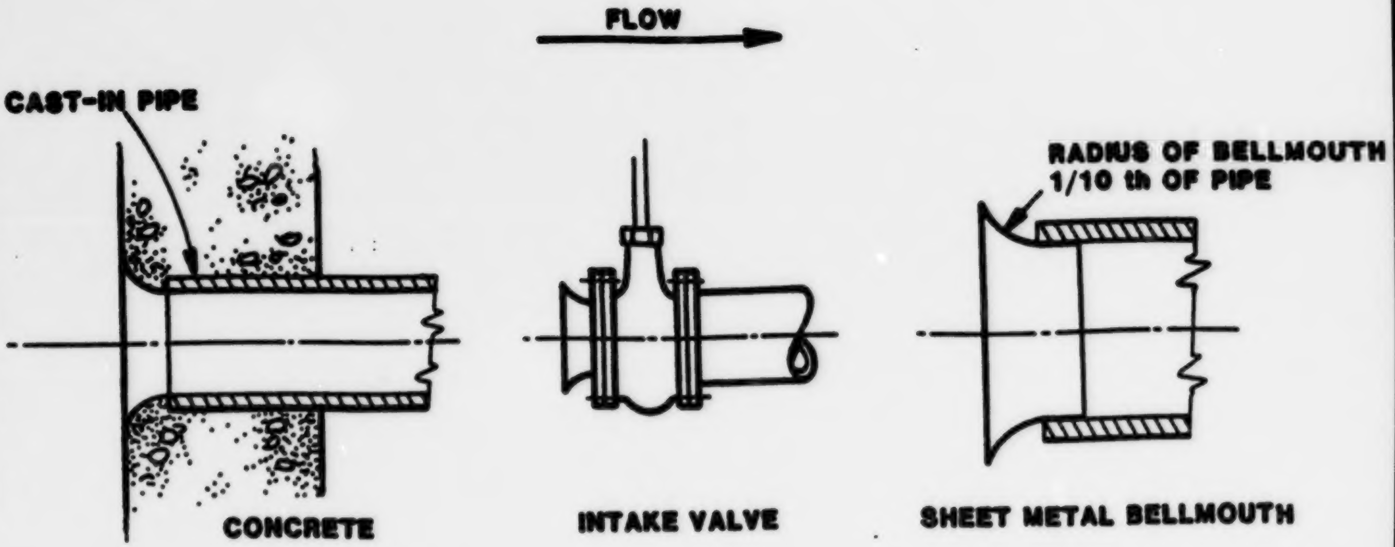
Excess nitrogen can be forced into solution in the penstock and this can cause fish disease in sever instances. Excess nitrogen can be caused by air leaks into the penstock, or penstock vortex at the inlet, or by cascades and waterfalls immediately upstream of the intake.

Excess nitrogen will be dispersed during passage of water through impulse turbines, but may not be effectively eliminated by reaction turbines. This point should always be considered on reaction turbine plants. One cure is to spread the turbine discharge out into a thin turbulent sheet over a gravel bed for some distance before discharge into the stream. On larger plants, professional assistance may be required to achieve an environmentally acceptable cure.

Fish will usually be partially descaled or killed whilst passing through reaction turbines. In cases where fish mortality is a concern, special intake screens and other preventative measures may be necessary.

Penstock Bellmouths

Penstocks should be provided with a bellmouth intake, otherwise water constriction at the end of the pipe may cause undesirable head loss.



CONCRETE

INTAKE VALVE

SHEET METAL BELLMOUTH

FIG.4-21PENSTOCK BELLMOUTHS

Some pipe suppliers stock bellmouths, but they also can be made up from 14 to 18 gauge galvanized steel. The important part is to ensure a smooth radius where the bellmouth connects to the pipe.

When using submerged valves, use brass trimmed valves. Submerged valves are much less liable to freezing. Use a flushing out pipe with this type of installation so that the reservoir can be drained for valve maintenance and intake cleaning.

Size of Intake

The necessary area of the intake is determined by the volume and rate of flow. The water velocity, as it passes through the trash rack bars, should not be more than two feet per second, and if excessive silt or frazil ice is involved, the velocity should be one foot per second or less. Canal intakes are often made half a foot per second.

Example:

12" penstock. Assume pipe I.D. = 11.5", velocity 6 ft/sec.

Area of pipe =

$$\frac{\pi D^2}{4} = \frac{3.142 \times \left(\frac{11.5}{12}\right)^2}{4} = 0.72 \text{ sq. ft.}$$

Volume per second = 6 x 0.72 = 4.32 cubic ft/sec.

If water flows through the trash rack at 2 ft/sec., the necessary clear area:

$\frac{4.32}{2}$ = 2.16 square feet

Assuming bars occupy 1/3 of available width,

Open area between bars = $\frac{2.16}{0.66}$ = 3.2 sq. ft.

The height is fixed in this example at 2'-6". Therefore, minimum width =

$\frac{3.25}{2.5}$ = 1.28 ft.

In the above example, the clear opening could be made a little shorter to increase the distance below water level and to increase the clearance above the bottom. A good size would be two feet square. Do not skimp on the size of intake. Larger than necessary size, together with heavy trash rack bars, will be superior in the long run. A good rule for sizing intake area is 2 square inches per gallon per minute.

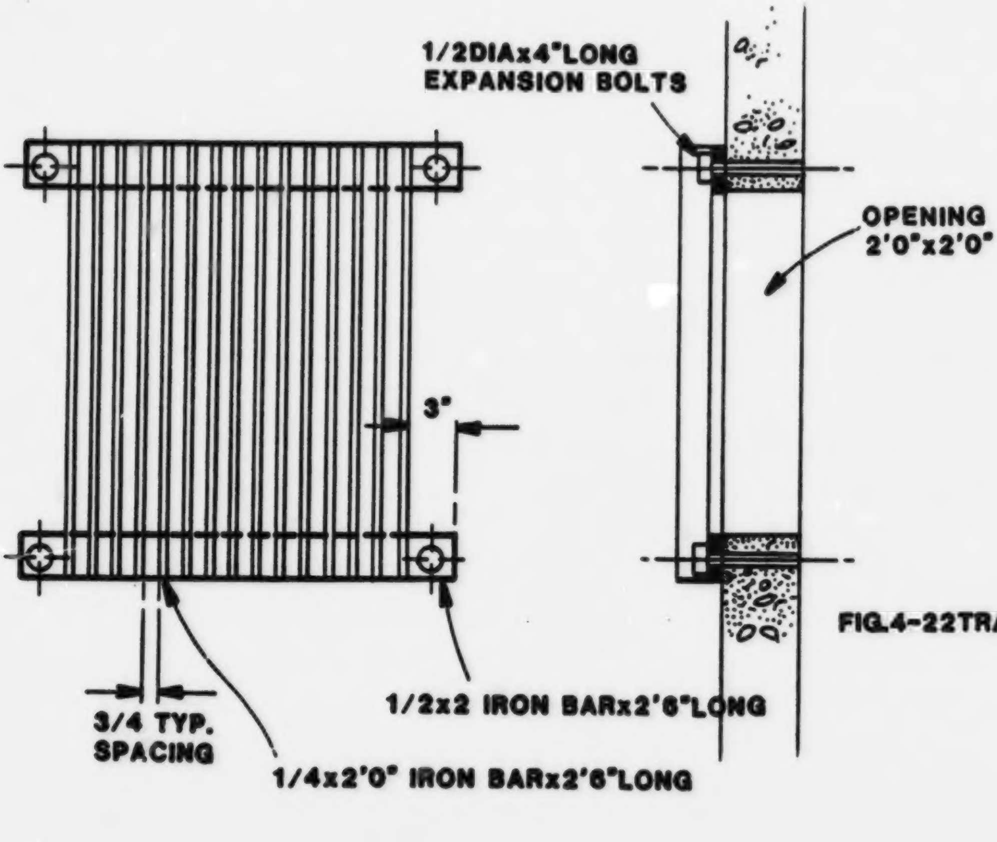

1/2DIAx4"LONG
EXPANSION BOLTS
OPENING
2'0"x2'0"
3"
3/4 TYP.
SPACING
1/2x2 IRON BARx2'6"LONG
1/4x2'0" IRON BARx2'6"LONG

FIG.4-22TRASH RA

Small Trash Rack

Rack bars consist of 1/4" x 1" steel bars welded to 1/4" x 2" mounting bars, having 3/4" spacing between bars. The general rule is: the clear opening behind the trash rack should be greater than twice the actual pipe diameter (in feet) each way, or an equivalent area if the opening is rectangular. For particularly silty water, or where frazil ice occurs, reduce the intake velocity to less than one foot per second and use a correspondingly larger intake. Where the required height of the intake area cannot be achieved whilst maintaining the required distance above and below the intake, a sloped rack is necessary to increase the area without increasing the height. See Fig. 4-22 for an example.

Sloping Trash Rack

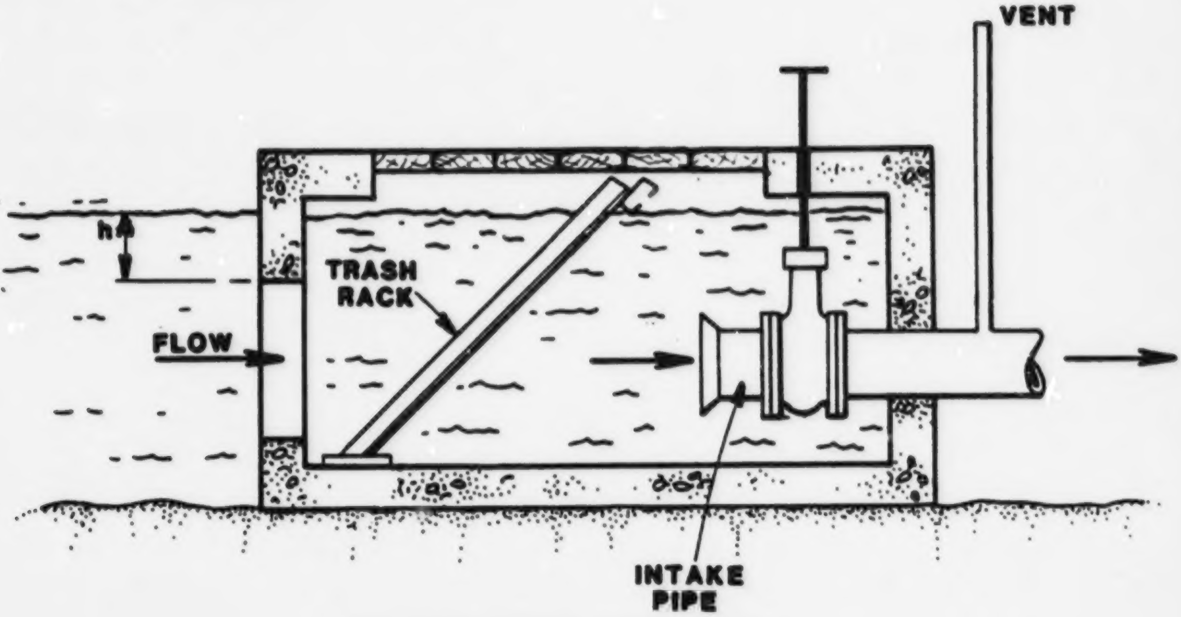


FIG.4-23SLOPING TRASH RACK

Figure 4-23, Sloping Trash Rack

A sloping intake has a greater effective area, and sufficient length to limit water velocity through the bars to one to two feet per second. With this design, trash can be raked up onto the access platform for disposal. Bars spacing can be somewhat wider for larger plants, up to about 1" clear space for 16" pipe. The front overhang is a stripper wall which will keep ice out of the intake. In northern areas, 'h' should be the distance beneath usual ice cover. This can be omitted where ice cover is only a few inches, or where frazil ice is not experienced. See Chapter Nine for further information on icing. Do not use horizontal trash racks.

Small Intake

A small intake is suitable for use where little if any ice is usual.

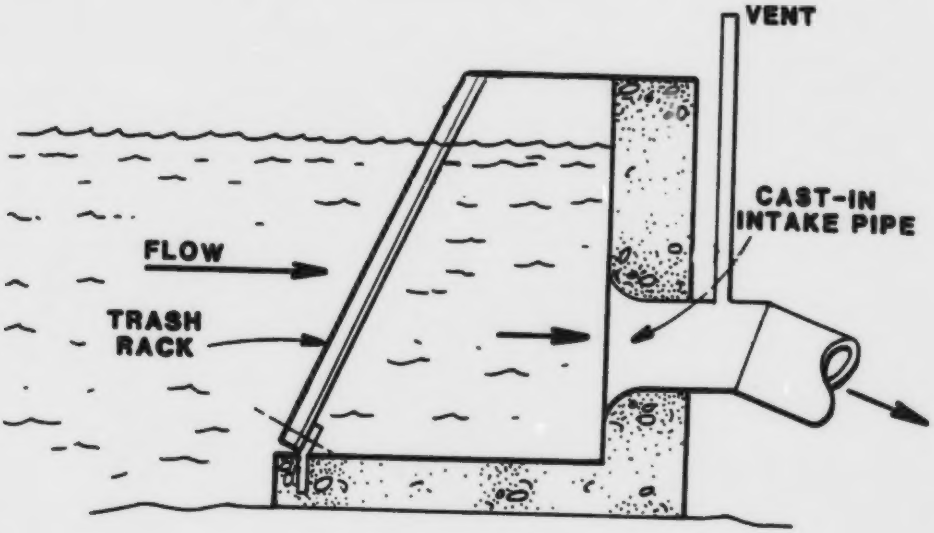


FIG.4-24SIMPLE INTAKE

Many other intake designs are possible depending upon the type of dam, availability of materials and personal preference. The following points should be remembered:

1. Inlet velocity past the trash rack bars should be one to two feet per second.
2. A clear area of at least two pipe diameters should be maintained all around the bellmouth.
3. Intake depth below the water surface with ice should be two pipe diameters.
4. The intake height above the bottom should be 1-1/2 pipe diameters but not less than 18".
5. A cleanout pipe should be provided, with the mouth near the intake. Water can be lowered to give access to the racks and intake valve where necessary.
6. Frazil and thick surface ice require special provisions.
7. Access to valves and trash racks must be safe and convenient.
8. On small timber structures, the intake can be built onto the upstream face.

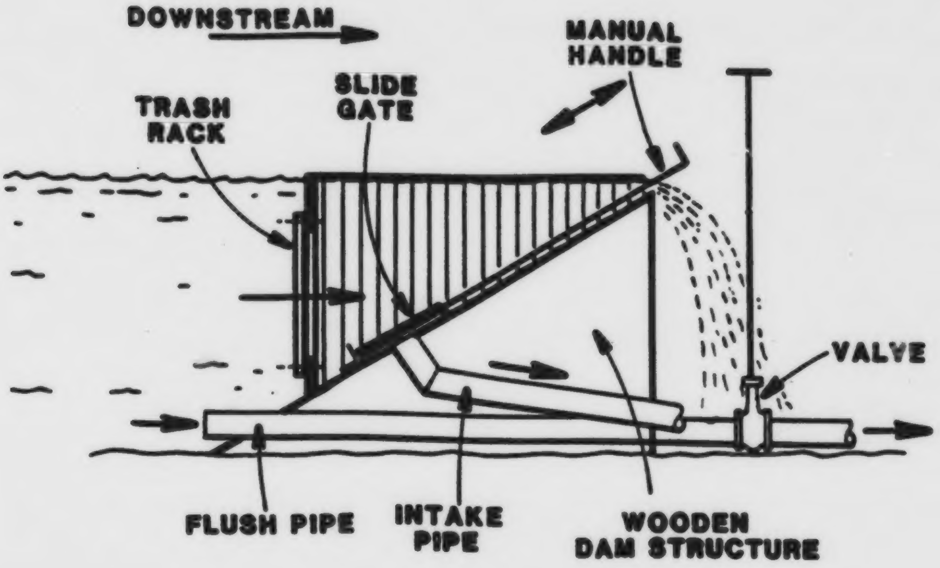

DOWNSTREAM
MANUAL HANDLE
SLIDE GATE
TRASH RACK
VALVE
FLUSH PIPE
INTAKE PIPE
WOODEN DAM STRUCTURE

FIG.4-25INTAKE ON TIMBER DAM

Intake Box on Damsack Dam

Damsack, which is sacks filled with dry, ready-mix concrete (see Section 4.1), is a convenient construction material you may wish to consider. Intake on damsack structures is built partway into the damsack structure. On small sites, a box welded from steel plate, and firmly anchored into the structure, is sometimes used.

Boxes welded from angle iron and pipe, should be a 2' x 2' cubic shape with trash racks on three sides. For trash racks on three sides. For trash racks, use 3/4" pipe flattened on the ends and anchored to the damsack structure.

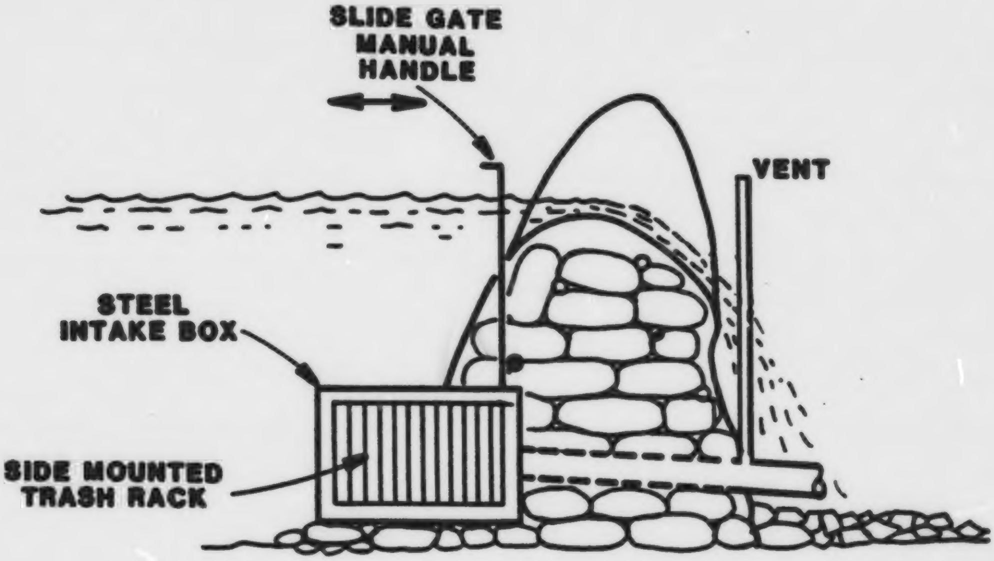

SLIDE GATE MANUAL HANDLE
VENT
STEEL INTAKE BOX
SIDE MOUNTED TRASH RACK

FIG.4-26STEEL INTAKE BOX ON DAMSACK DAM

Concrete Intake on Rock or Earth Fill Dam

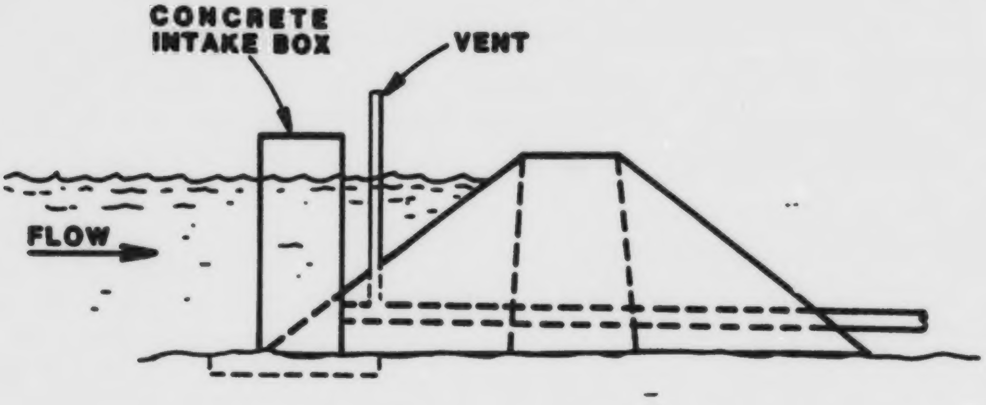


FIG.4-27INTAKE ON EARTH OR ROCKFILL DAM

Trash racks should be flush with the concrete, and should be cast-in or bolted onto guides for inserting a stop-log gate. Some types of intakes use a wall between the intake and the valves so that the valves are located in a dry area. This should be done if the reservoir cannot be drained.

Fig. 4-28 to 4-36 illustrate various intake arrangements and accessories.

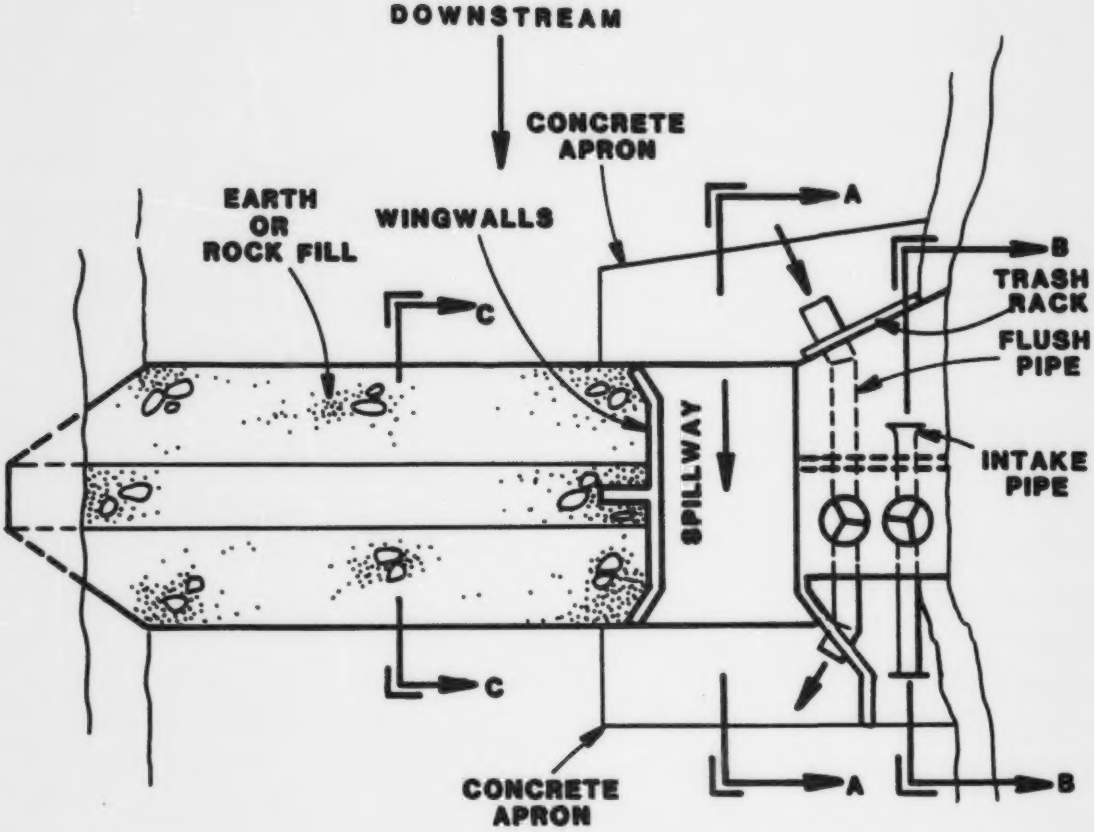

DOWNSTREAM
CONCRETE APRON
EARTH OR ROCK FILL
WINGWALLS
A
B
C
TRASH RACK
FLUSH PIPE
SPILLWAY
INTAKE PIPE
C
CONCRETE APRON
A
B

FIG.4-28EARTH OR ROCKFILL DAM(PLAN)

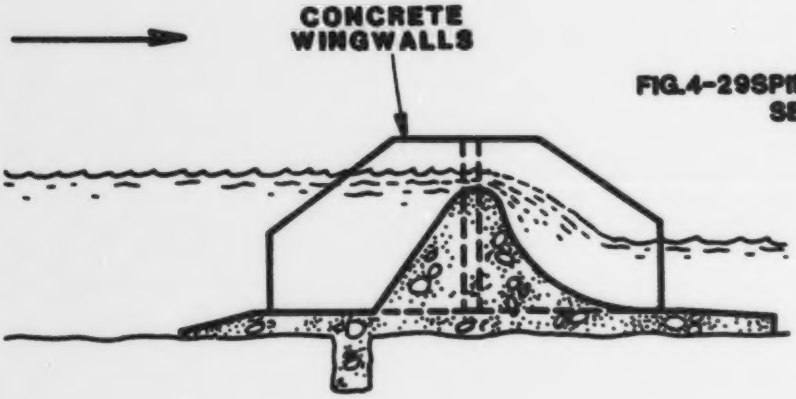
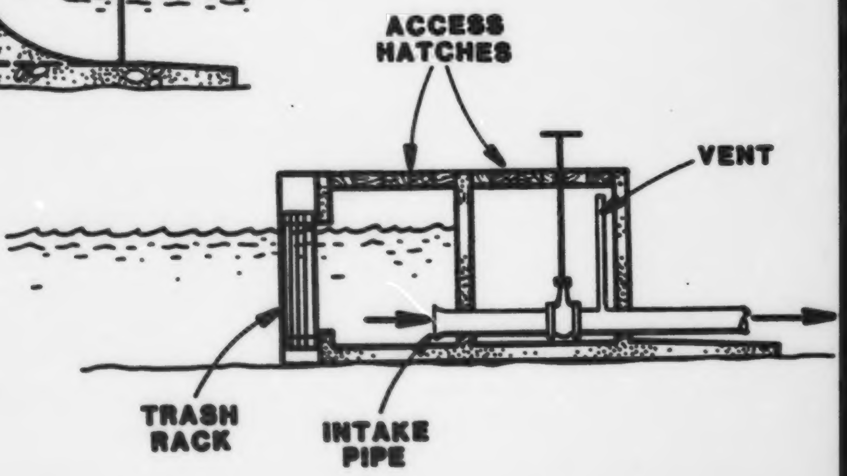

CONCRETE WINGWALLS

FIG.4-29SPILLWAY SECTION

FIG.4-30INTAKE SECTION


ACCESS HATCHES
VENT
TRASH RACK
INTAKE PIPE

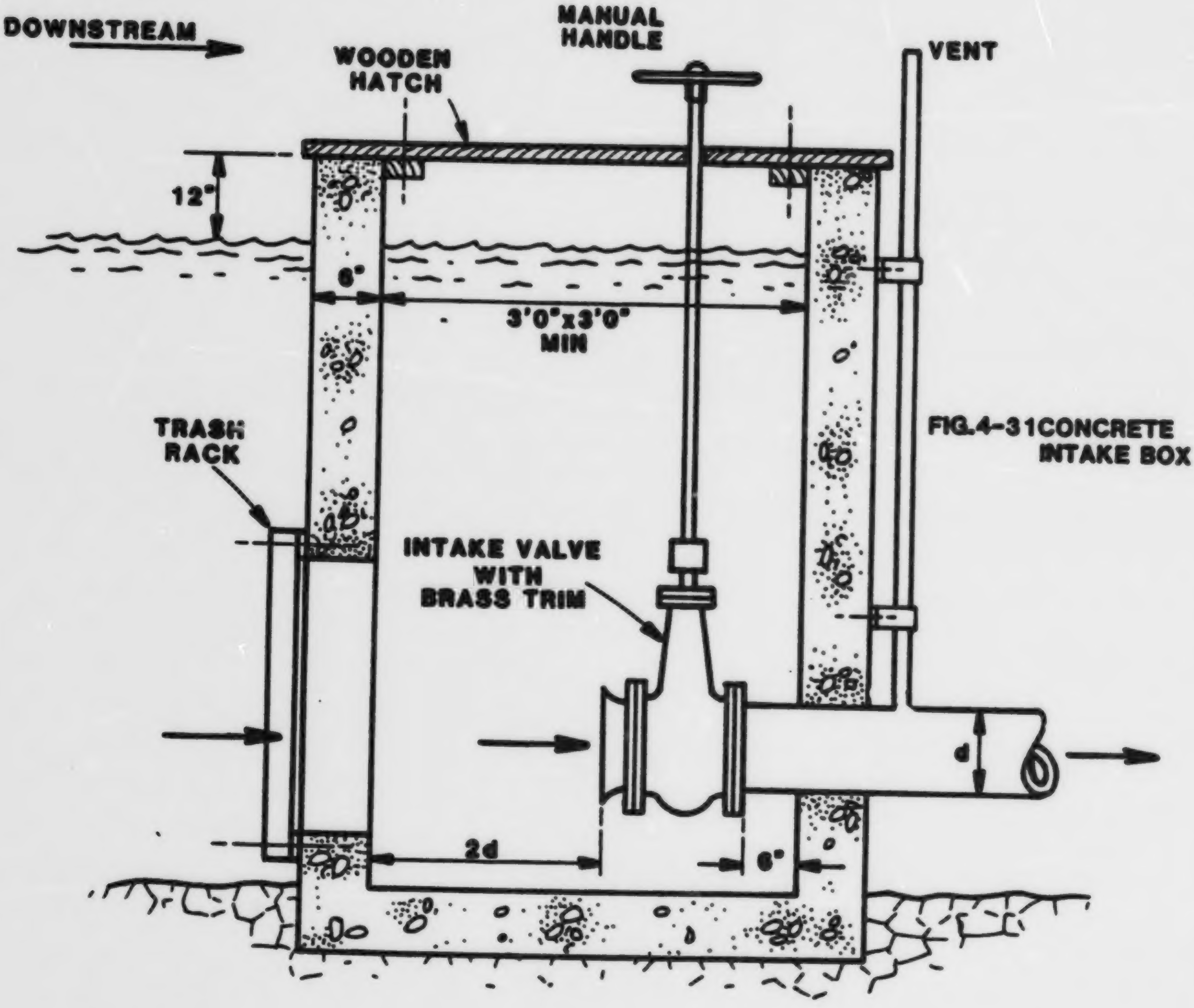

DOWNSTREAM
MANUAL HANDLE
WOODEN HATCH
VENT
12"
6"
3'0"x3'0" MIN
TRASH RACK
INTAKE VALVE WITH BRASS TRIM
d
2d
6"

FIG.4-31CONCRETE INTAKE BOX

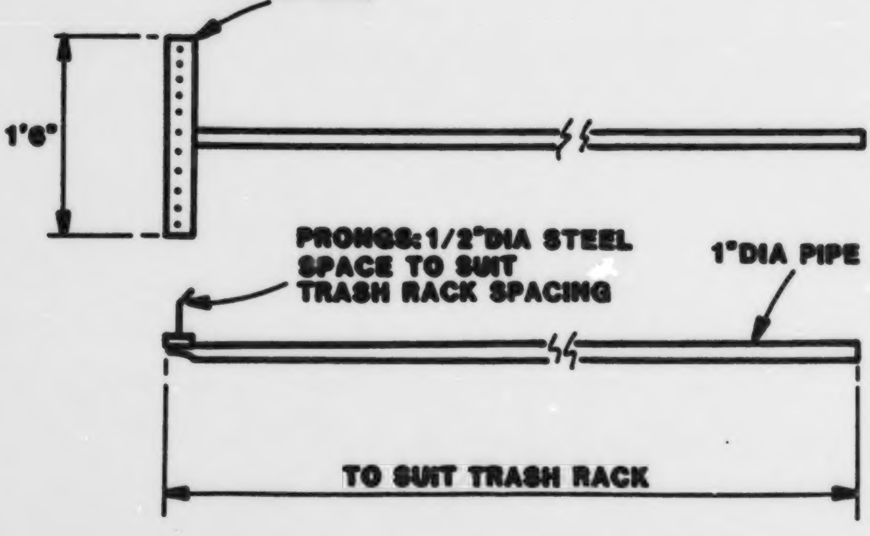

1/4"x2"BAR
1'6"
PRONGS: 1/2"DIA STEEL SPACE TO SUIT TRASH RACK SPACING
1"DIA PIPE
TO SUIT TRASH RACK

FIG.4-32TRASH RACK RAKE

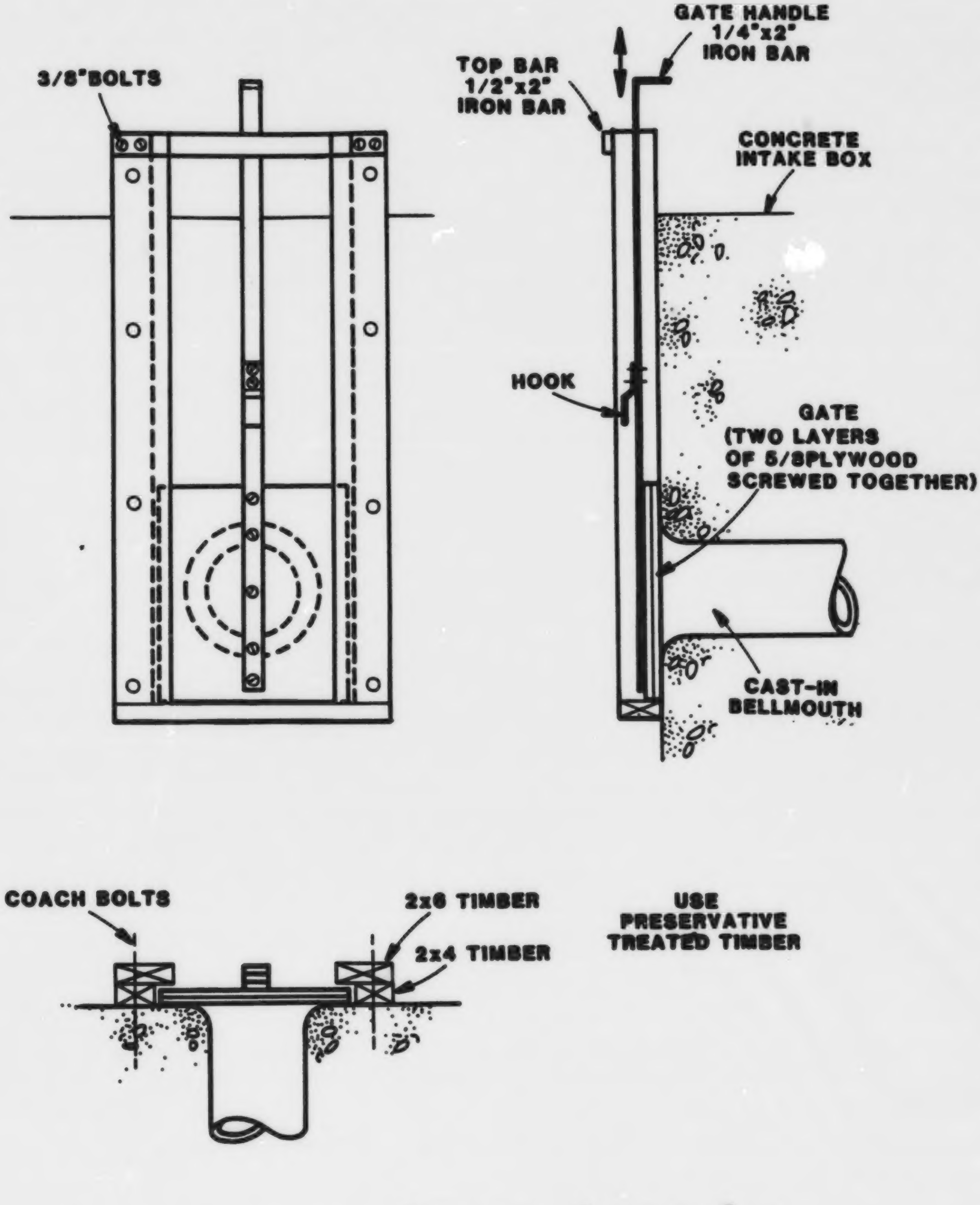

3/8"BOLTS
GATE HANDLE
1/4"x2"
IRON BAR
TOP BAR
1/2"x2"
IRON BAR
CONCRETE
INTAKE BOX
HOOK
GATE
(TWO LAYERS
OF 5/8PLYWOOD
SCREWED TOGETHER)
CAST-IN
BELLMOUTH
COACH BOLTS
2x6 TIMBER
2x4 TIMBER
USE
PRESERVATIVE
TREATED TIMBER

FIG.4-33 PENSTOCK SLIDING GATE

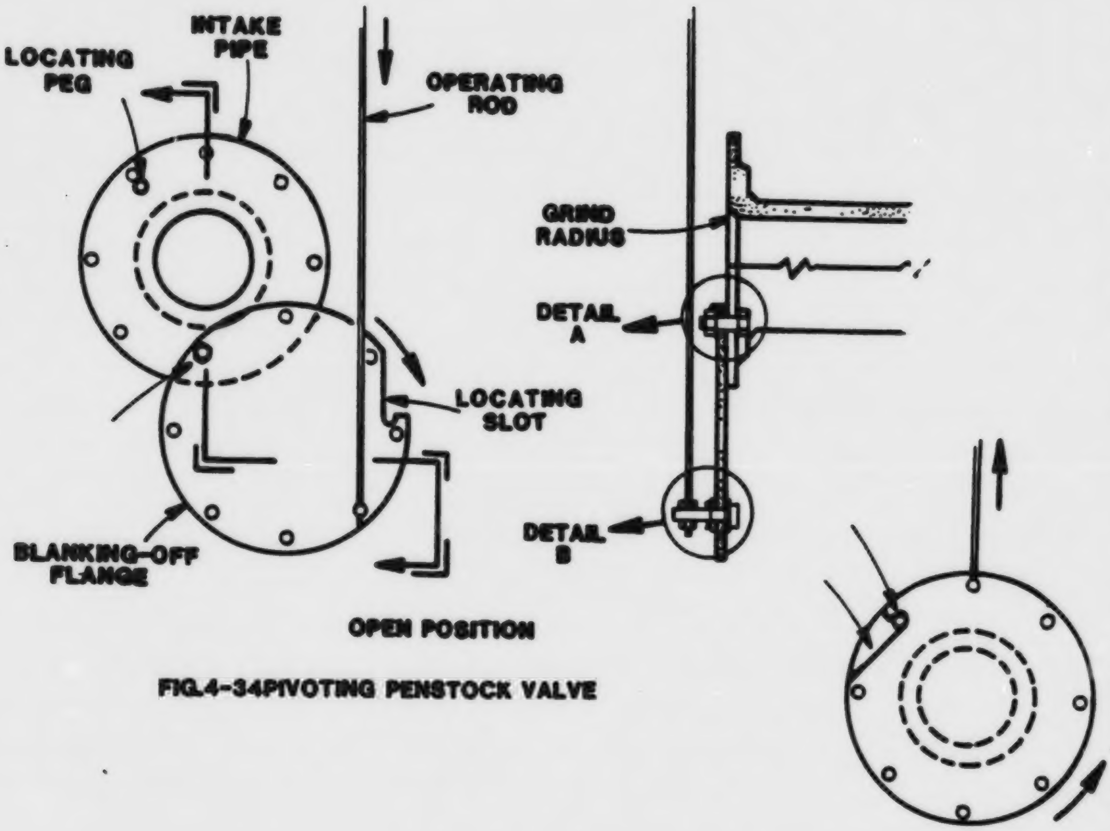

INTAKE PIPE
LOCATING PEG
OPERATING ROD
GRIND RADIUS
DETAIL A
LOCATING SLOT
DETAIL B
BLANKING-OFF FLANGE
OPEN POSITION
CLOSED POSITION

FIG.4-34PIVOTING PENSTOCK VALVE

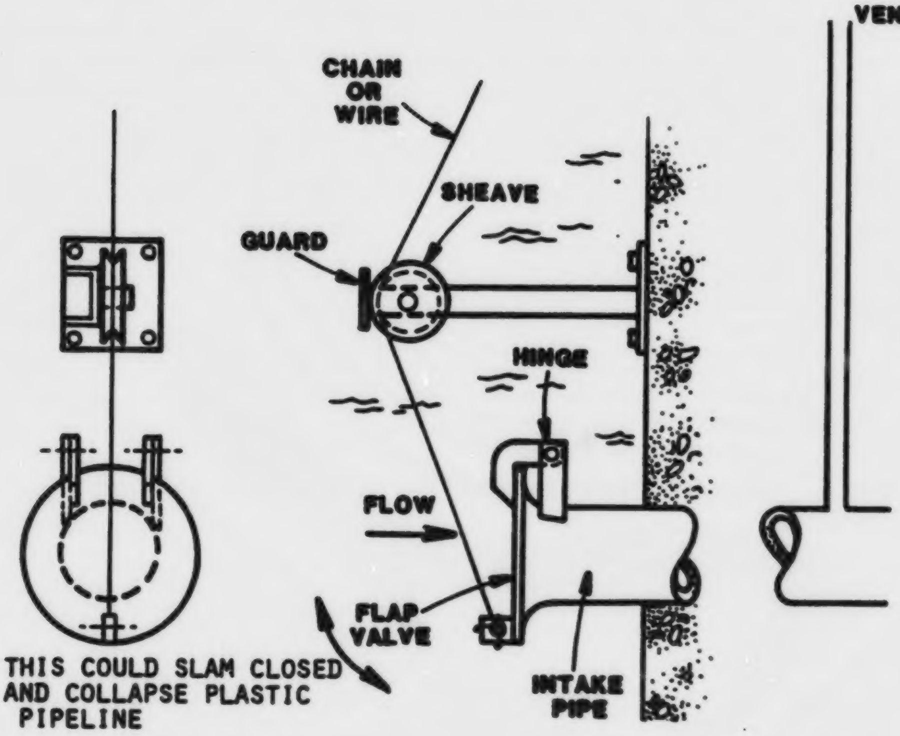

VENT
CHAIN OR WIRE
SHEAVE
GUARD
HINGE
FLOW
FLAP VALVE
INTAKE PIPE
THIS COULD SLAM CLOSED AND COLLAPSE PLASTIC PIPELINE

FIG.4-35PENSTOCK FLAP VALVE

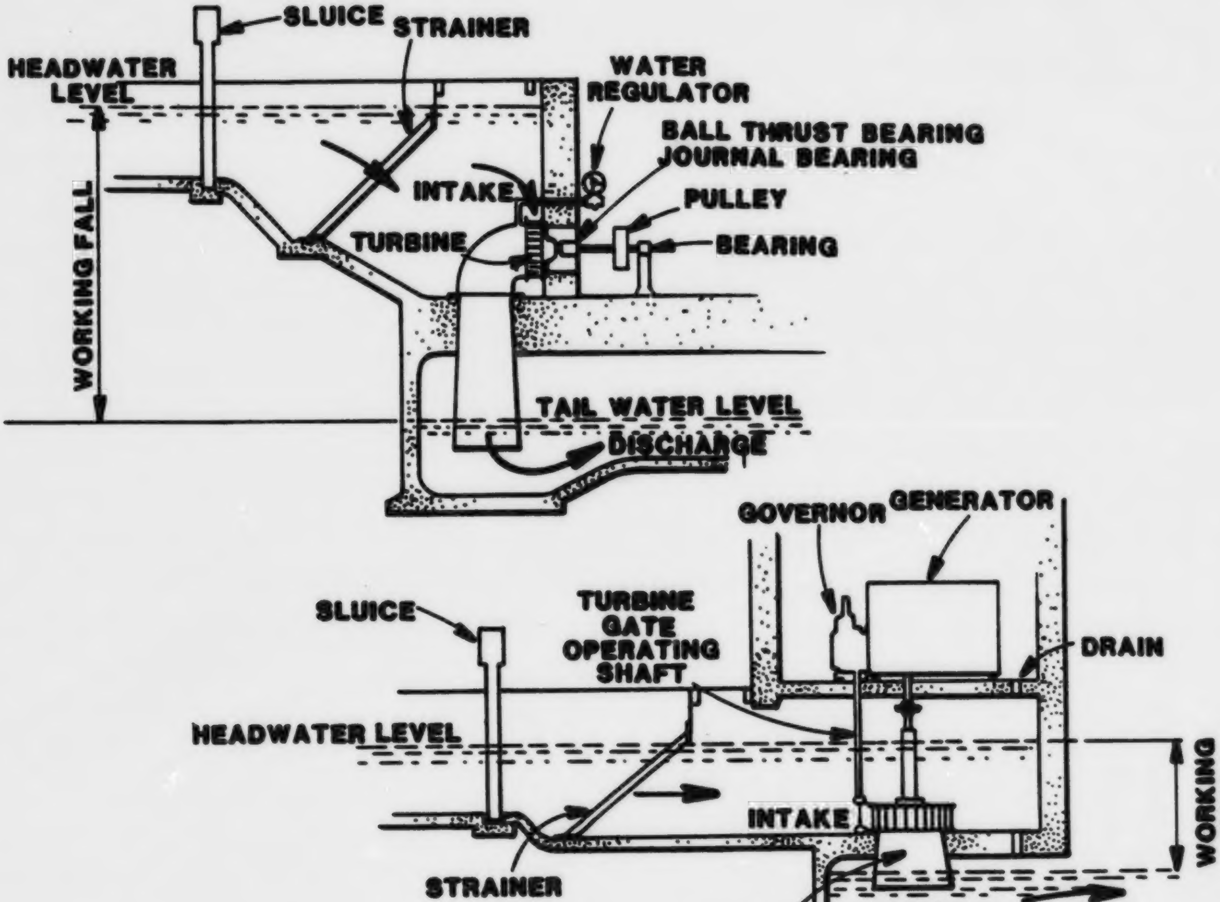

SLUICE
STRAINER
HEADWATER LEVEL
WATER REGULATOR
BALL THRUST BEARING
JOURNAL BEARING
INTAKE
PULLEY
TURBINE
BEARING
WORKING FALL
TAIL WATER LEVEL
DISCHARGE
GOVERNOR
GENERATOR
SLUICE
TURBINE GATE OPERATING SHAFT
DRAIN
HEADWATER LEVEL
WORKING FALL
INTAKE
STRAINER
TURBINE
DISCHARGE
AIR BREATHER PIPE
VALVE
TURBINE
HEAD WATER LEVEL
REGULATOR WHEEL
SLUICE
STRAINER
TAIL WATER LEVEL
DISCHARGE

FIG.4-36EXAMPLES OF LOW HEAD INTAKE

4.3 DIVERSIONS

As the name implies, diversions are intake structures which divert water away from a stream or river which is too large to dam up, or direct water from one stream to another at a lower elevation.

Diversion on Small River

A 90° diversion will attract less debris into the intake. The river bed should be dredged -- the deeper the better -- especially where heavy ice may form. The diversion will have to be cleaned out occasionally as gravel and sand will settle in the calmer area.

Refer to Figure 4-37.

Diversion with Concrete Settling Basin

A diversion with a concrete settling basin should be large enough to reduce the water velocity to half a foot per second. Overall length should be 45 feet to 75 feet, and the diversion can be built using concrete, gabions or gunited embankments.

Slow water flow is necessary to allow sand and silt to settle out. The slower and longer the transit time, the cleaner the water entering the penstock will be.

Refer to Figure 4-38.

Diversion on Large Stream

The diversion dam in fast moving streams can often be made using heavy boulders, placed by a bulldozer during the dry period or in winter. Usually the flow needs to be obstructed only to achieve a rise of two feet or so.

Refer to Figure 4-39.

Intake with Sediment Tank

An intake with sediment tank can be used in a small stream, or as a diversion on large streams. Settling tanks can be made from old oil tanks, boilers, or precast concrete pipe; the bigger the better. A manufactured, self-cleaning sediment tank is available.

Refer to Figure 4-40.

Stillage Basin Using Gabions and Natural Features

Stillage basins are usually necessary in fast moving streams which tend to contain silt and sand. These streams will move quite a lot of gravel and small boulders during run-off. Occasionally a pool from which to draw water can be created, otherwise a sediment tank must be provided.

Refer to Figure 4-41.

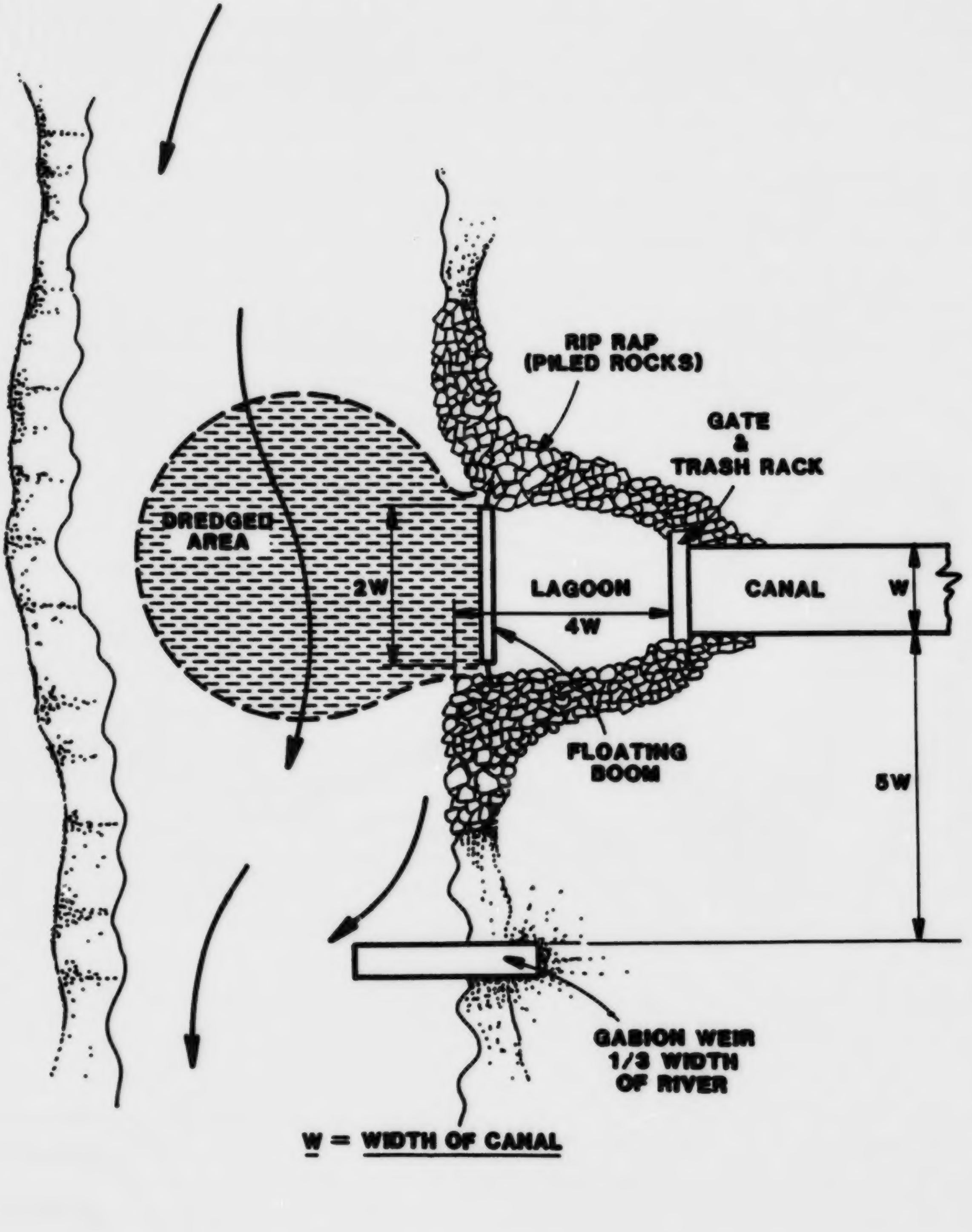

RIP RAP
(PILED ROCKS)
GATE
&
TRASH RACK
DREDGED
AREA
2W
LAGOON
4W
CANAL
W
5W
FLOATING
BOOM
GABION WEIR
1/3 WIDTH
OF RIVER
W = WIDTH OF CANAL

FIG.4-37DIVERSION ON A SMALL RIVER

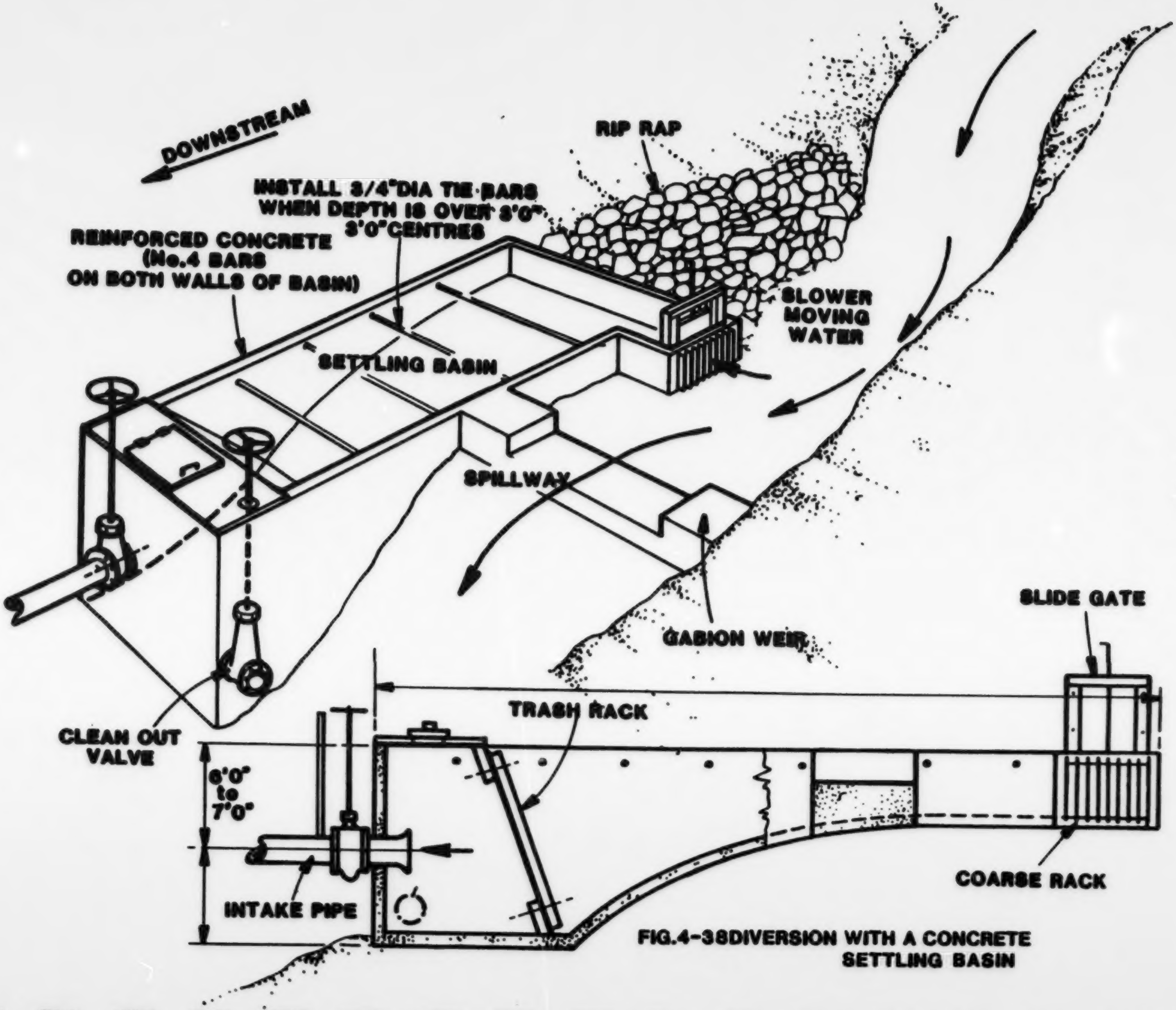

DOWNSTREAM
RIP RAP
INSTALL 3/4"DIA TIE BARS
WHEN DEPTH IS OVER 3'0"
3'0"CENTRES
REINFORCED CONCRETE
(No.4 BARS
ON BOTH WALLS OF BASIN)
SLOWER
MOVING
WATER
SETTLING BASIN
SPILLWAY
GABION WEIR
SLIDE GATE
CLEAN OUT
VALVE
TRASH RACK
6'0"
to
7'0"
INTAKE PIPE
COARSE RACK

FIG.4-38DIVERSION WITH A CONCRETE SETTLING BASIN

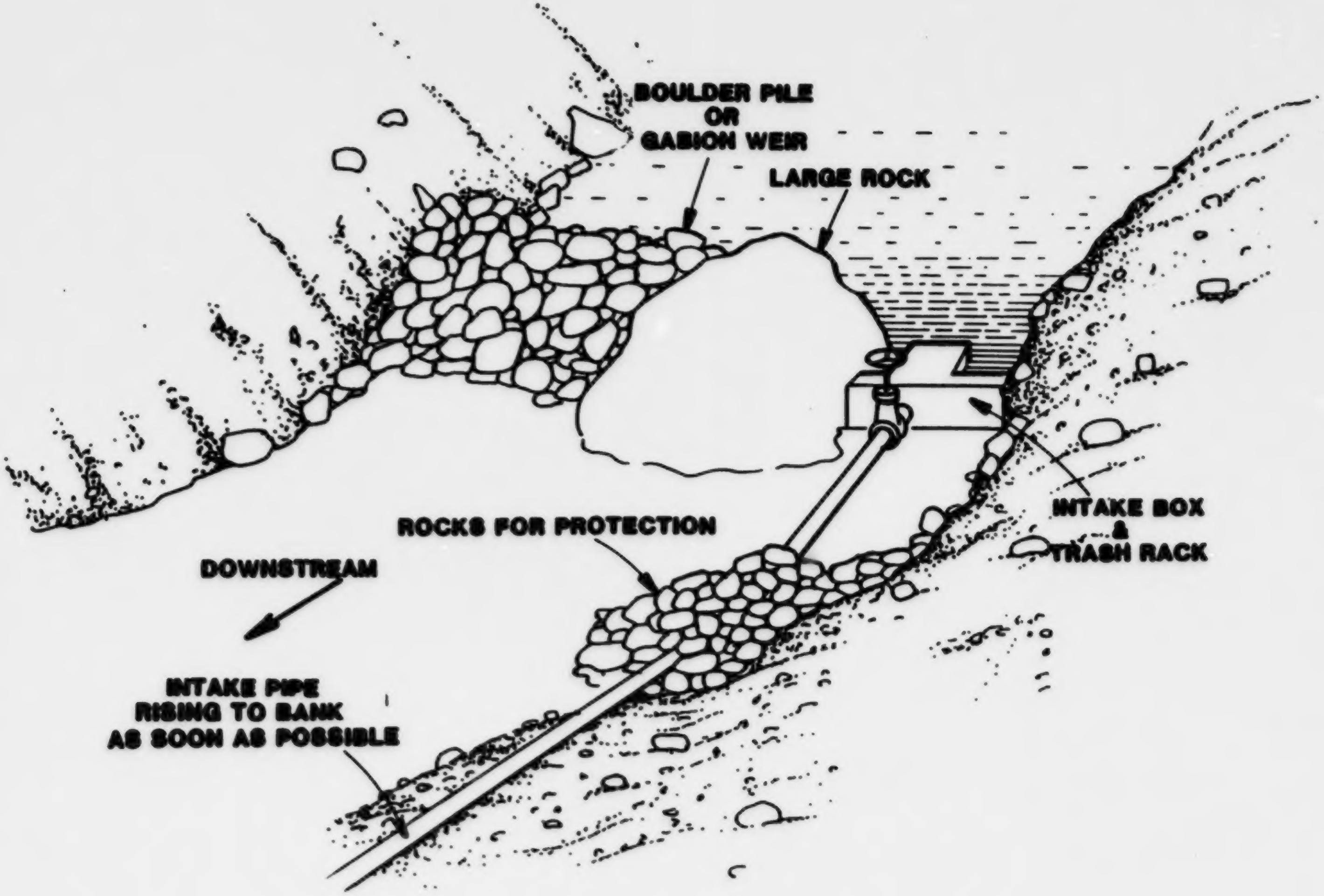

BOULDER PILE
OR
GABION WEIR
LARGE ROCK
INTAKE BOX
&
TRASH RACK
ROCKS FOR PROTECTION
DOWNSTREAM
INTAKE PIPE
RISING TO BANK
AS SOON AS POSSIBLE

FIG.4-39DIVERSION ON A LARGE STREAM

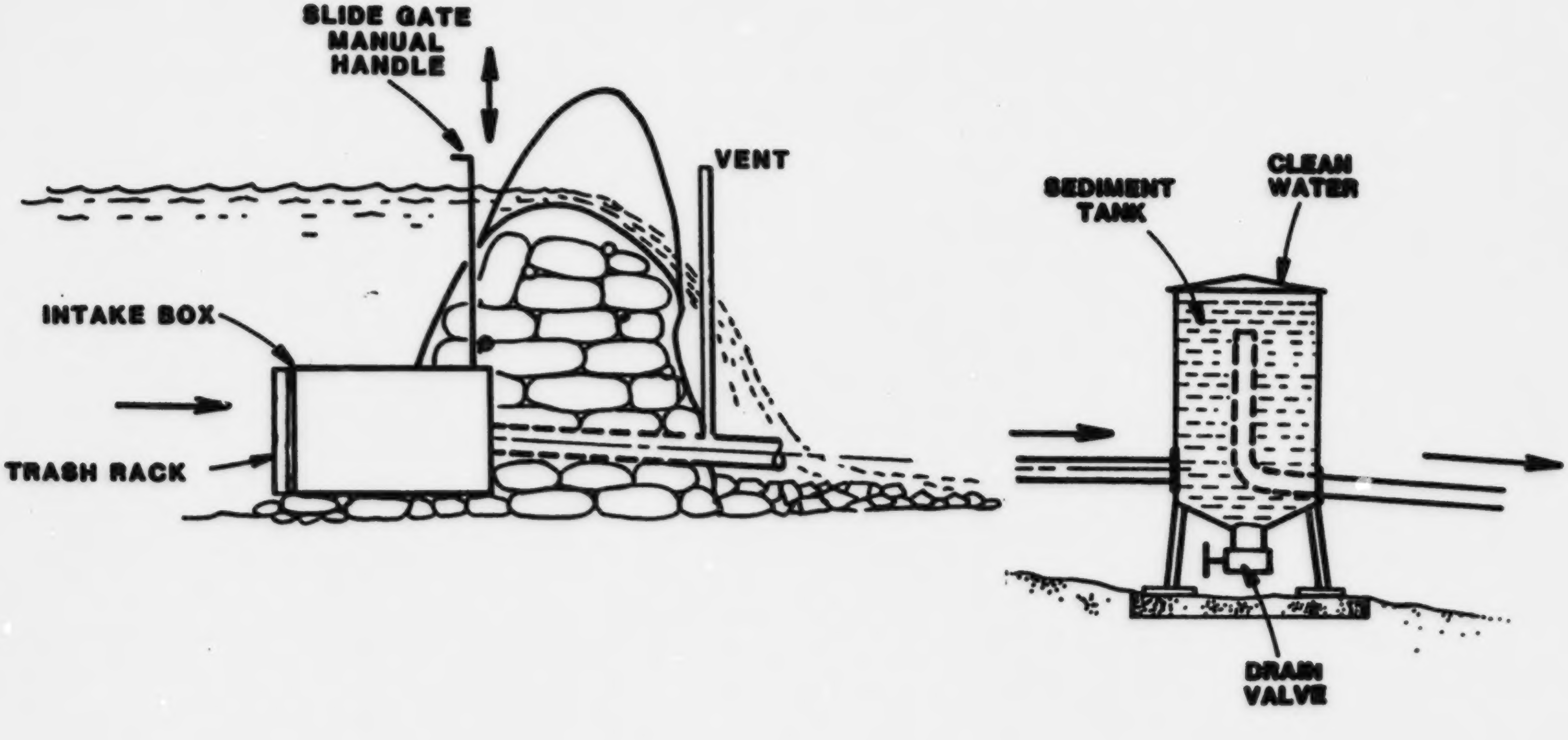

SLIDE GATE MANUAL HANDLE
VENT
INTAKE BOX
TRASH RACK
SEDIMENT TANK
CLEAN WATER
DRAIN VALVE

FIG.4-40SMALL STREAM DIVERSION & SETTLING TANK

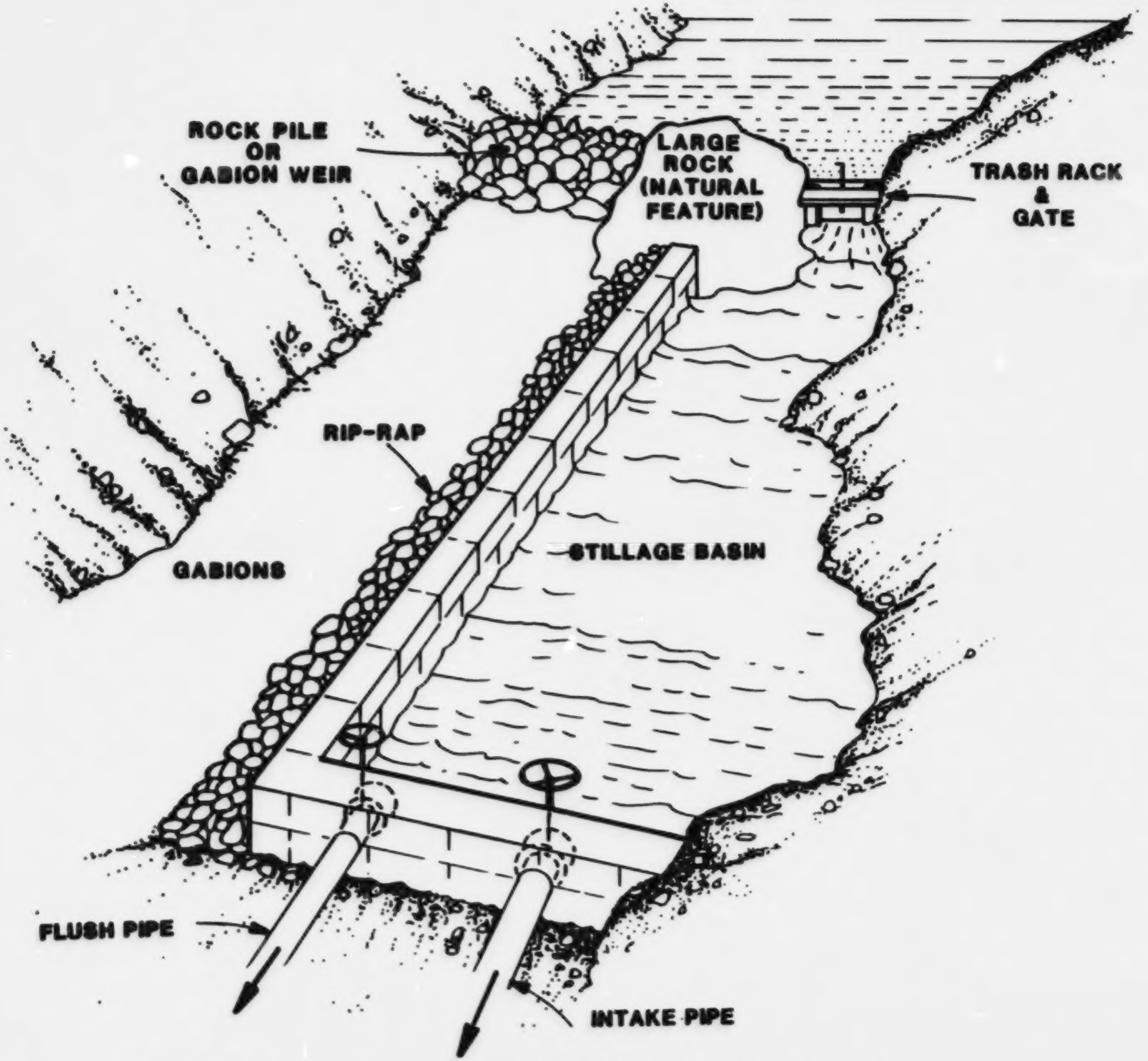

ROCK PILE
OR
GABION WEIR
LARGE
ROCK
(NATURAL
FEATURE)
TRASH RACK
&
GATE
RIP-RAP
STILLAGE BASIN
GABIONS
FLUSH PIPE
INTAKE PIPE

FIG.4-41STILLAGE BASIN USING GABIONS & NATURAL FEATURES

Canal Intake

Note: Headpond at connection point with the penstock. The side spillway is necessary to handle overflow when the plant is shutdown. Coarse trash racks are installed at the canal intake, with finer ones at the penstock intake.

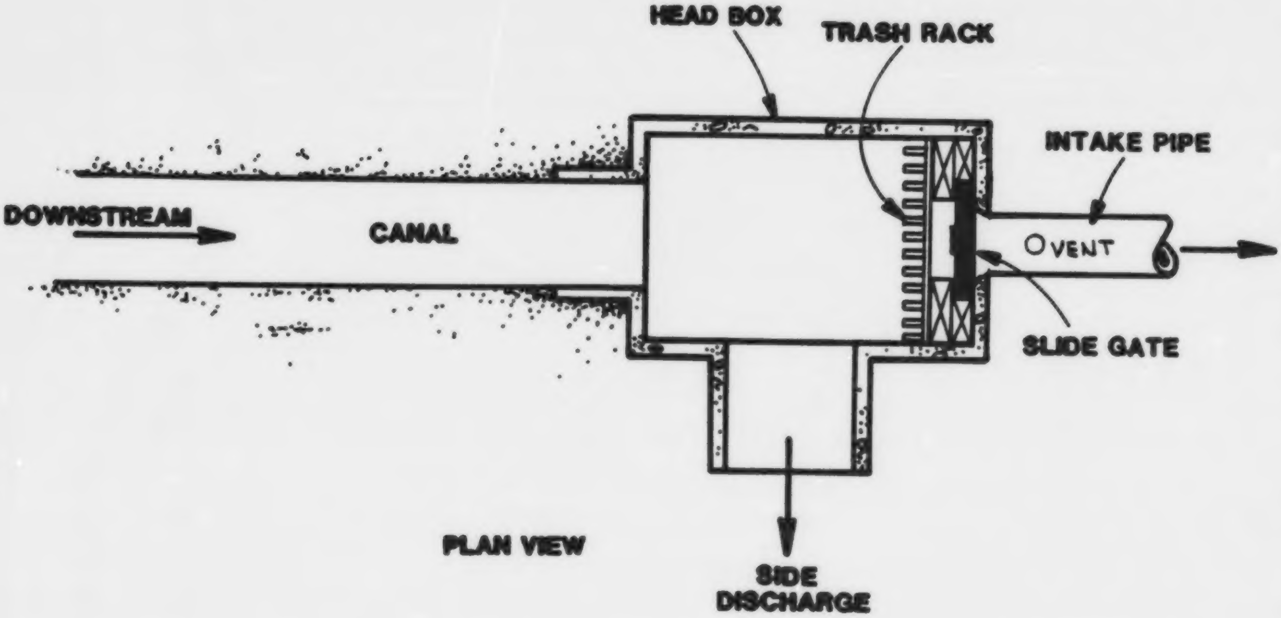

HEAD BOX
TRASH RACK
INTAKE PIPE
DOWNSTREAM
CANAL
O VENT
SLIDE GATE
PLAN VIEW
SIDE DISCHARGE

FIG.4-42CANAL INTAKE

Intakes on Existing Dams

Installing a hydro power intake on an existing dam is usually possible, but doing so is extremely inadvisable before undertaking a thorough engineering assessment. In all cases, the results of a preliminary assessment should be available prior to committing time and funding to in-depth studies or planning.

4.4 MAINTENANCE OF DAMS AND INTAKES

All dams and inlet structures require a certain amount of maintenance. All structures should be inspected several times per year, and particularly following the spring run-off.

Dams

Newly-built dams will usually settle, but careful construction, choice of materials and adequate compaction will limit the settlement. During the first season, dams should be inspected for signs of undue leakage and settlement at least once per week. The reservoir will slowly fill with sand and debris, so that flushing down and cleaning is a regular maintenance item. A good time to flush the dam is during the spring run-off when the extra flow will scour out sand and gravel deposits.

Silt and sand entering the reservoir drop out to form a distinct delta, Figure 4-43. Ideally, the water flow in the reservoir should be lower than half a foot per second to permit good settlement. This delta can often be seen underwater, and its rate of progession can be measured. On many sites sufficient pondage to precipitate sand and silt is not possible to achieve, and in these cases a separator tank may be necessary. See the section on intakes, Section 4.2.

Earth fill dams can be imperiled by burrowing animals such as marmots. If you are troubled such animals, cover the dam with small-mesh chicken wire or similar material, pegged or weighted into place. Remove vegetation other than grass and small shrubs from the surface of the dam, and remove trees which could fall onto the dam.

When the water is drawn down for bottom cleaning, observe the upstream face of the dam for signs of piping, cracking or slumping. Restore as necessary. Remove water logged branches, etc. Clean out the bottom of the intake box. Examine the banks of the reservoir for slumping, because occasionally the banks will slough into the reservoir. If this has happened or appears to be likely, the banks must be protected. Gabions are a sure cure for sloughing, or alternatively a rock berm piled against the bottom and extending about a third of the height will solve the problem. Draw down the reservoir periodically, possibly once a year.

Note: Earth fill dams should be drawn down as infrequently as possible, and should not be left drawn down. If earth fill dams are permitted to dry out, serious cracks may develop.

Spillways

Spillways will occasionally catch debris which may result in a rise in water level. Debris such as branches and trees may deflect water onto a sensitive part of the structure.

The effect of the water coming over the spillway during flood conditions should be noted. The force of the water must be broken, otherwise the downstream end of the dam may be undermined. Large rocks should be placed at the foot of the fall for this reason. More rocks may have to be added.

Intakes

The intake area in the reservoir should be kept free of sand, gravel, and debris. Observe the rate of build-up on the reservoir bottom so that periodic flushing and cleaning can be done in time to prevent sand and debris from being drawn into the penstock.

The trash rack should be cleaned regularly: on some sites, daily cleaning may be necessary in the autumn to remove accumulated leaves. If leaves are a problem, a floating boom can be installed upstream of the intake.

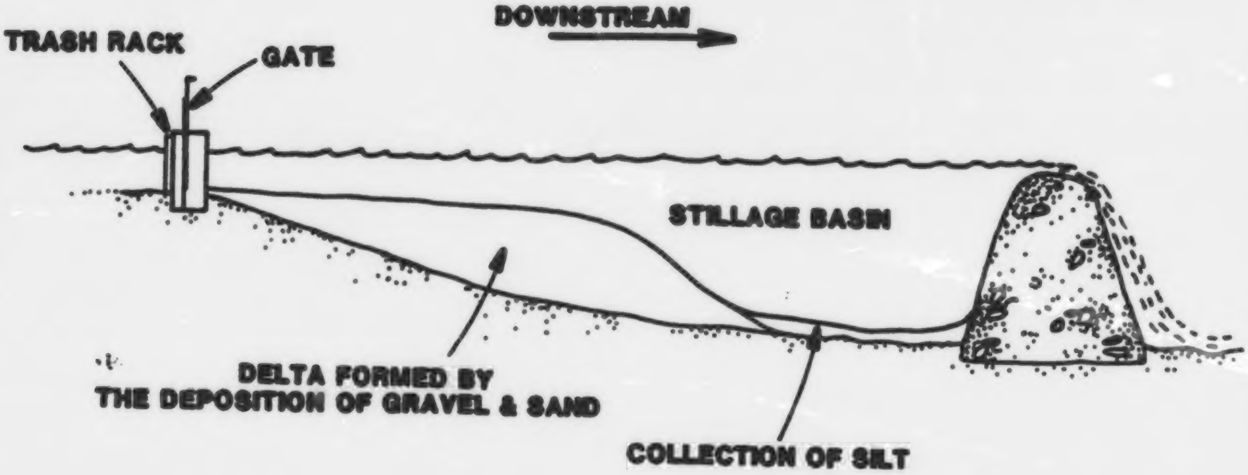

DOWNSTREAM
TRASH RACK
GATE
STILLAGE BASIN
DELTA FORMED BY THE DEPOSITION OF GRAVEL & SAND
COLLECTION OF SILT

FIG.4-43SAND DELTA IN RESERVOIR

Valves

Valves normally require very little maintenance, but should be operated occasionally because valves have a tendency to freeze up when left unused for long periods of time.

Valves will eventually leak at the spindles, and when this occurs, the spindle packing can be tightened.

Prolonged use and exposure to sand will eventually cause wear on the internal sealing surfaces. If the leakage becomes excessive, the valve should be rebuilt.

All types of penstock valves must be operated slowly to avoid setting up water hammer. Cast iron valves can be broken by water hammer.

When hydraulic, air, or electrically operated valves are in use, a periodic check should be made to ensure that the valve is in operating condition. This should be done once or twice each year during regular maintenance shutdowns.

Penstocks

Newly-installed penstocks should be inspected at regular intervals, because some movement will take place as the pipe supports settle. Some adjustment or repairs to saddles may occasionally be necessary. Expansion joints should be measured to make sure that they are centred over the pipe joint (see "pipes" for explanation). Check all thrust blocks for evidence of movement, and increase the size and weight, if necessary.

PVC penstocks are subject to slow surface degradation where exposed to direct sunlight. They can be painted with anti-ultraviolet paint on exposed surfaces, or can be wrapped with heavy roofing paper tied on with galvanized wire. Preferably cover with earth.

Steel penstocks may eventually show signs of deep rusting, and if this occurs, coat with bituminous paint. Larger buried steel penstocks are often cathodically protected, but this must be done at the time of installation. Cathodic protection will indefinitely extend the life of steel pipe.

Cut trees which are likely to fall and place them alongside the penstock for extra protection.

General

Conditions will stabilize in a few years, and experience will determine both the necessary frequency of maintenance and the items prone to trouble.

Large reservoirs can be stocked with fish, and can provide many hours of recreation. Where the dam is accessible to children, fencing and other precautions may be necessary.

Remember that a few hours of maintenance per year can save you days of downtime and expensive repairs.

4.5 FACTORS AFFECTING COSTS AND CONSTRUCTION

Certain types of dams will be labor intensive, while others can be more equipment intensive. Much depends on the site's accessibility to vehicles. For instance, selecting a rock fill dam is unwise if vehicular access to the site is not possible. On the other hand, gabion weirs can often be built using rock in the immediate vicinity, with cages and other necessary components carried to the site.

In many instances, gabion weirs will be the most cost effective, particularly when rock is available on site. Gabion weirs are also very practical, since they are less liable to damage by extreme flood conditions. According to the material available, the cages can sometimes be filled with a front end loader, and the corresponding labor content is low. Concrete quantities are fairly small and can be mixed on site. A good powder man can provide you with an ample supply of fractured rock of the correct size.

Rock fill dams will be economic, providing the site is accessible to trucks and contractor's equipment.

Timber dams will be inexpensive, provided you own the logs. This type of dam has a relatively short life, and will need repairs and eventual replacement in 10 to 20 years.

Small concrete dams may be economic when the site is accessible to ready mix delivery. Otherwise time and labour content can be high.

Damsack can be economic in remote areas inaccessible to vehicles, although packing the cement to the site is exhausting labor. This type of dam is rapidly and easily built, and is reliable in service; this makes it a natural first choice for small isolated dams and intakes.

For sites which are difficult to reach by foot, do not overlook the use of a helicopter. Although helicopter time is expensive, a helicopter can easily pay for itself. The perspective view you get of the stream as a whole will often enable you to select a better site than you could do on foot. Mark the spot with a dye marker.

Estimating Costs

1. Select the preferred type of dam and intake. Work out dimensions and compute the quantity of fill, concrete, reinforcing bar, formwork, timber, and all other components.

2. Estimate costs for all "bought out" parts such as valves, pipes and trash rack.

3. For gabion weirs, determine the number and size of gabion crates. Estimate materials for the intake and concrete for grouting the surfaces.

4. Estimate the volume of earth moving at the dam for foundation preparation, access, etc.

5. Estimate transportation costs for all materials. Estimate additional labor required, either yours or the paid labor.

Handling and placing of rock, fill, concrete, rebar and site clearing is usually computed on a cubic yard or cubic metre basis. Establish local costs for all such material, and summarize:

cost of materials delivered to site __________
cost of materials in place __________
cost of all "bought out" components __________
cost of access road where used __________
cost of additional labor __________

Contingency sum, add 15% __________

TOTAL ESTIMATED COST __________

Now discuss the project with a contractor, and get one or more estimates. The contractor's estimate will only be as good as your quantity survey and your description of what is required. Ask for detailed estimates based on estimated quantities. This will enable you to determine possible savings by doing certain parts of the work yourself. The Contractor's experience will show up gaps in your estimates, or areas for negotiation. For clearing of foundations and work on access roads, some contractors will estimate on an hourly basis. Excavated material occupies about 1.3 times the space that it did when it was in the ground. Contractors will estimate cost on the volume in the truck, so multiply your estimated quantities by 1.3.

4.6 PENSTOCK DESIGN

The penstock is a major expense, and in potential hydro sites the penstock cost will determine the economic viability of the project. Low head sites tend to be less affected by penstock costs, but this advantage may be lost if a canal is necessary. The efficiency of site utilization and costs are also affected by the choice of penstock material, since the pipe friction of plastic pipe is less than that of steel.

Selection of the penstock diameter is an economic problem, with the following fundamental elements:

(a) the value of the energy lost to pipe friction; and

(b) size of penstock and the value of the share of interest charges or amortization attributable to the penstock.

The sum of these two factors equals the annual cost attributable to the penstock. The economic problem is to find the pipe size which will reduce the annual cost to a minimum. In other words, look for the best balance between head loss and installed cost. Increasing size increases the cost and annual charges, but also decreases head loss and thus increases the amount of energy which can be generated. In general, it will pay to change to a larger pipe size when the value of the extra energy available is greater than the annual interest charges on the additional capital required for the larger pipe. This type of problem occurs fairly often in engineering.

Some approximate rules are given as a starting point:

1. The average slope of the penstock should be more than 12 feet in 100 feet; (unless it's relatively short) otherwise the cost will be excessive.
2. For plastic pipe, the total head loss should be about five percent, and for steel, seven percent to eight percent total.
3. Penstock water velocity in steel pipe should not exceed six feet per second, while in plastic pipe the velocity should not exceed five feet per second. Moderate values of head loss usually give velocities below this. Short, steep penstocks or short large diameter penstocks often use velocities up to ten feet per second or more.
4. Where loads are fairly well established, with little anticipated load growth, the plant can often be optimized for 75 percent full load. Nearly all small domestic hydro plants operate with load factors well below 75 percent, although full capacity may be needed to meet short term peak loads. The penstock losses and velocity will be higher during peak loads than if the plant were designed for continuous full load. The exceptions to the above are utility grid plants and those governed by electronic load controllers, both of which may be designed for continuous full load conditions.

Plotting pipe friction loss curves for several pipe diameters and pipe types is advisable. Friction losses rise in a relatively straight line for some time, and then swing sharply upward. The pipe size chosen should be the one which will meet full load conditions somewhere near the upper end of the straight line portion of the curve.

Penstock Loss Curve

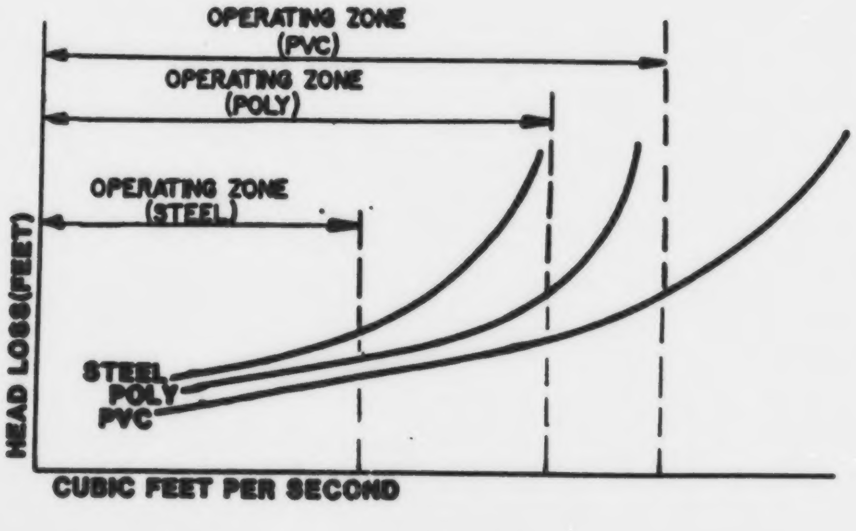


FIG.4-44PENSTOCK LOSS CURVE

A range of pipe materials is available. In practice, the choice narrows down to three. Steel has been the traditional material, but pvc and polyethylene pipe are attractive because of low internal friction and low weight. Choice usually depends finally on installed cost. Cost comparisons should be made, as occasionally one or another type will show to advantage on a given site. Polyethylene has an advantage on some sites, since, unlike steel or pvc, it can be frozen solid without damage.

Procedure for Sizing the Penstock

Follow these steps:

1. List the basic site parameters. These are: quantity of water, (cfs), gross head, length of penstock, number of bends, valves, or fittings in the penstock.

2. Draw on graph paper a scale profile of the penstock.

3. For plastic pipe, determine the necessary pressure class or series.

4. Determine the size of plastic pipe which will give a velocity of five to six feet per second and reasonable friction loss, assuming the high pressure size is used throughout.

   For steel pipe, choose the internal diameter as above. The wall thickness will be determined by internal pressure, handling and backfilling requirements.

5. Determine miscellaneous losses from valves, etc.

6. Determine whether lighter gauges of pipe can be used on the uphill sections, and recalculate losses.

   If using steel pipe, one size will often be used. When reducing the pipe wall thickness on upstream sections, the small diameter changes usually do not significantly affect overall losses. When using plastic pipe, the wall thickness becomes large as the pressure rating goes up and can significantly affect losses and water velocity.

7. Total all losses and recalculate plant power output. Usually a choice must be made between two sizes of pipe, or between types of material.

   In these cases, work out the installed cost and the kW output for each alternative.

8. Finally, submit your penstock profile to several pipe suppliers. Ask for their recommendations as to type and class of pipe: these recommendations will serve as a check on your own calculations. Most pipe suppliers can give ballpark

estimates on installation costs. For final estimates, get quotations from local contractors, or work out your own costs including equipment time, shipping, labor, etc.

Pipe Loss Formulas

Various pipe loss formulas are available, and the two most commonly used are Williams & Hazen and Manning's. These formulas depend upon friction factors which are tabulated below. The nomograph, (Figure 4-45) uses Williams & Hazen friction factors according to the type and condition of the pipe. When using the nomograph, select whichever friction factor is applicable to your site.

Friction Factors	Williams & Hazen	Manning's
new welded steel pipe, over 18"dia.	140	0.0125
old steel pipe	110-130	0.017
concrete, good work	140	0.013
concrete, poor work	105	0.017
pvc and polyethylene	140	0.012
new steel pipe 14" dia. or less	120	0.015

Balancing of Losses

Say for instance, that a penstock can be buried most of the distance, but a steep rocky pitch necessitates an above ground section. To avoid freezing of this section, the water velocity in it can be increased to ten feet per second by using smaller pipe. The resulting higher head losses can be made up by using oversize pipe in another part of the route. Velocity and losses can be balanced so that overall losses remain the same. This compromise can also be worked when the pipe must be supported along the steep banks of a canyon or in other exposed areas. A constant gradient enabling the pipe to drain is essential, particularly when freezing weather is likely.

Cold Climates

Velocity in above ground penstocks must usually be raised to avoid freezing. As a general rule, velocities above seven feet per second will not freeze, but it is recommended that penstocks be buried below the frostline.

The Pipe Laws

(a) The head loss varies directly as the length of pipe.
(b) The head loss varies almost as the square of velocity.
(c) The head loss varies inversely as the diameter to the fourth.
(d) The head loss depends upon the roughness of the pipe.
(e) The head loss depends upon viscosity and inversely temperature.

For method of calculating water hammer, refer to relevant section.

Pipe Loss:Approximate Method: Use of Nomograph, Figure 4-45

This nomograph can be used for steel, pvc, and polyethylene pipe. Use a C-value of 150 for polyethylene and pvc, a C-value of 140 for new steel pipe, 30" and over, a C-value of 125 for good used steel pipe, and a C valve of 130 for new pipe below 12" diameter. Note: The effect of sidewall friction is more critical in small diameter pipes, especially when the water velocity is above 7 feet per second. For this reason, you should be more conservative when calculating losses on small penstocks, especially when they are of considerable length. To use this chart, align a straight edge between any two variables in the same side of the pivot line. The straight edge is then pivoted on the pivot line to the third known value, and the desired quantities read.

For example. Discharge 2.3 cfs at five feet per second. Find pipe size:

Lay a straight edge on the line joining 2.3 cfs and five feet per second. The pipe size can be read, 10" pipe. To find head loss: mark the point where the straight edge intersects the pivot line when spanning 10-inch pipe and five feet per second. Swing the straight edge from the intersection point through C = 150. Pipe head loss is read at seven feet per 1000 of pipe.

The following examples use alternative methods by way of illustration.

- Nomograph for plastic pipe.
- Pipe loss tables for steel pipe.

The methods give quite close comparative results.

4.7 CHARACTERISTICS OF PIPES

Plastic Pipe

At least 17 types of plastic pipe are currently available. For penstock use, this can be reduced to two:

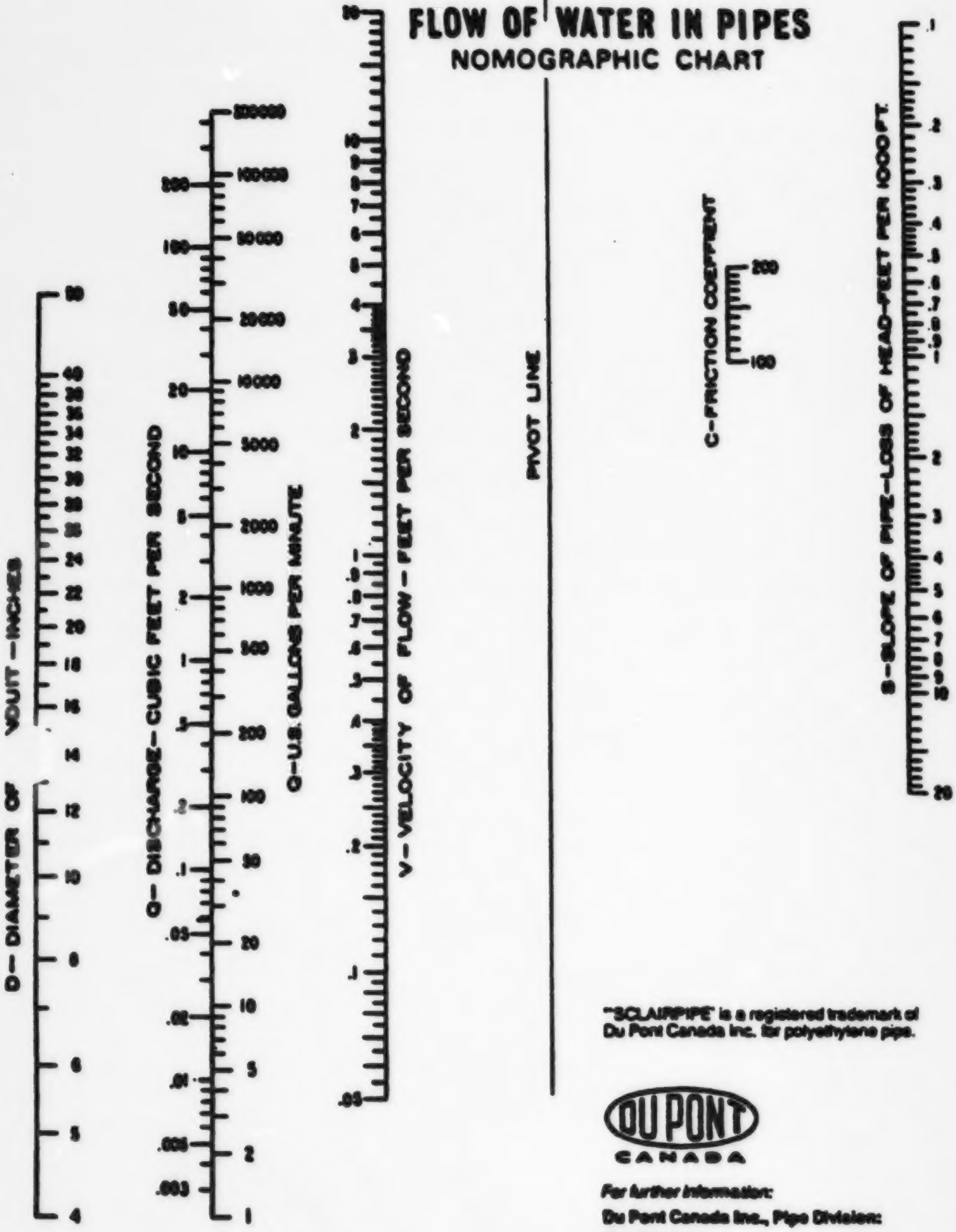
(a) polyvinyl chloride (PVC);
(b) polyethylene (PE).

Most plastic pipes are available in sizes up to 60 inches. All manufacturers publish their own recommendations for use, size specifications, and installation techniques. Pipe sizes are either National Pipe Size (NPS) class, or series numbers, but many other sizes and specifications, including metric, are available.

When you have established the necessary internal diameter, discuss your needs with one or more suppliers who will recommend wall

FLOW OF WATER IN PIPES

NOMOGRAPHIC CHART


D— DIAMETER OF CONDUIT —INCHES
50
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
5
4
Q— DISCHARGE— CUBIC FEET PER SECOND
200
100
50
20
10
5
2
1
.5
.2
.1
.05
.02
.01
.005
.003
Q—U.S. GALLONS PER MINUTE
200000
100000
50000
20000
10000
5000
2000
1000
500
200
100
50
20
10
5
2
1
V— VELOCITY OF FLOW— FEET PER SECOND
30
10
9
8
7
6
5
4
3
2
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
.05
PIVOT LINE
C—FRICTION COEFFICIENT
200
100
S—SLOPE OF PIPE—LOSS OF HEAD—FEET PER 1000 FT.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
10
20

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Du Pont Canada Inc. for polyethylene pipe.

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FIG 4-45

DU PONT
CANADA

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thicknesses and other details. Suppliers will normally check your hydraulic computations if requested to do so, and will list necessary fittings, etc. For reasons of economy, wall thickness schedules will usually change along the line as pressure increases. Where you have settled on a supplier, be sure to follow his instructions and techniques which may differ from those of other suppliers.

Polyethylene pipe stands up to freezing better than PVC, but both become very brittle at low temperatures.

Plastic pipe has a high damping factor when exposed to water hammer and is much less affected by it. Water hammer computations are quite complex, so should be done for you by the pipe manufacturer, or an engineer. See Figure 4-48 to Figure 4-55 for plastic pipe dimensions.

NPS Pipes

Steel pipes under 12" diameter conform to NPS (National Pipe Size), and ANSI or ASTM Schedule specifications.

Schedule Pipe

Pipes are also made in accordance with pipe schedules which run from schedule 10 through schedule 160. The outside diameter is equal to the listed diameter in sizes 14" and larger and does not vary with changing wall thickness. Bore size must be checked when performing hydraulic computations, because bore sizes vary with different standards of pipe.

Aluminum Pipe

Thick wall aluminium pipe is made to the same sizes as stainless steel pipe. Aluminum irrigation pipe is a thin wall product, available in sizes up to ten inches, but eight and ten inches are rarely used.

Aluminum Irrigation Pipe

Size	Working Pressure, Lbs/sq.inch (psi)
3	255
4	220
5	185
6	150
8	-
10	-

Working pressure is the maximum allowable, and for penstock purposes, indicates the maximum water hammer pressure. Aluminum pipe is joined by band and latch connectors for ready assembly and breakdown. Lengths are 30 and 40 feet, and available dimeters 3,4,5,6,7, and 10 inch sizes.

Caution must be taken when using aluminum pipe for hydro penstocks, because the bond and latch connectors are liable to blow out on high static pressure. Working pressure should not be more than 25 percent of rated pressure.

Asbestos Cement (Transite)

Ductile, aluminum or asbestos cement pipe normally would not be used for penstocks except when there is low head, or when the pipe is available as inexpensive surplus material.

Wood Stave

Wood stave pipe construction was extensively used at one time for penstocks, pipelines, and water tanks. It is less liable to frost damage than either plastic or steel, and expansion joints are not required. For small hydro, wood stave has a range of usefulness in long pipelines which convey water to a point where head can be developed. Wood stave has largely been superceded by plastic pipe, but can be competitive in sizes larger than 30 inches.

Wrapped Pipe

When corrosive material such as clay, or soils containing sulphite or chloride are involved, pipe can be wrapped with alternating layers of coal tar pitch and kraft paper, spiral wrapped plastic, or sprayed plastic. Additional protection can be achieved through the use of sacrificial anodes or cathodic protection.

Culverts

Corrugated culverts are a useful alternative to canals as a means of conveying water to a point where head can be developed. They can be installed in a trench up to about the midline, with the joints sealed with mastic. Culverts may also be fully buried for frost protection. Culverts are designed to run only partially full. Instructions for calculation of size and details for installation are available from manufacturers. They can be very useful for turbine discharge pipes.

Jointing Technology

Steel pipe can be welded, or joined by means of flanges or couplings. Most steel penstocks are welded with a few flange connections at valve locations and at convenient places along the route. Occasionally penstocks are welded into manageable lengths of 80 to 160 feet, with the lengths connected by means of flanges, expansion joints or couplings. Welding requires end preparation of the pipe, so this requirement should be specified when purchasing pipe. Welding operators should be certified for pipeline or overhead welding, and should be qualified with a pressure ticket for high pressure lines. Pipe having a wall thickness up to about 5/16" can be 'weld-prepped' onsite by grinding a 45° angle on the ends.

Plastic Pipe

Polyvinylchloride (PVC) pipe can be supplied for either gasketted bell and spigot joints or cemented joints. With cemented joints, the cement/solvent is applied to both surfaces to be joined, and after a temperature determined time period, the spigot end is forced into place. This must be done by mechanical means for pipes over 6". Cement joints may not be reliable if made under condition of low temperature or high humidity (rainfall). Gasket joints have a gasket inside the bell end which must be the correct way around. (Check with supplier). Special lubrication is smeared over the spigot end, and assembly is made by forcing together. Sizes above six or eight inches require mechanical means (pushed together using the backhoe, come-along, etc.) Do not attempt to sledge hammer the joints together as this leads to cracked bell ends.

Polyethylene (PE) pipe is joined by fusion welding in a special jig. If damaged, the ends of the pipe must be trimmed on the jig. The two ends are clamped and for a specified period are heated with a hot metal plate between the ends. When conditions are correct, the plate is swung out of the way and the pipes forced into contact by the jig mechanism. Properly done, the joint is as strong as the rest of the pipe. The jig must be rented from the pipe maker and is available in either gas or electric heated types.

Flanges can be installed in the same jig. A range of pipe fittings such as bends and tees is available.

Flanges and other fittings are butt welded. Temperatures, heating time and joining pressures must be closely regulated if reliable joints are to be made. Readers who wish to utilize plastic pipes should obtain manufacturer's installation manuals which contain detailed instruction and illustrated examples. Pipe loss tables, installation practice and much other useful information are given in the references. Each type of plastic pipe has a range of flanges and fittings designed specifically for use with the pipe material. Both imperial and metric pipe are available in plastic, and care must be taken when purchasing flanges and fittings. Flanges are used to connect plastic pipe to steel pipe, however, you must specify that requirement. Plastic flanges are easily overtightened to failure, so manufacturer's instructions on bolt torque must be followed, gaskets are necessary.

Pipe flanges come in standard sizes to fit any diameter, pipe schedule, or working pressure. The nember and size of the bolts is a part of the standard, and various types of gaskets are available. For flanged joints, rubber gaskets are commonly used except for very high pressure which requires special materials.

For small hydro use, steel pipes are usually either welded, or joined by means of flange or expansion couplings. There are flanges which can be screwed onto a threaded pipe, but these must not be employed on penstocks because of the weakening effect of the threads.

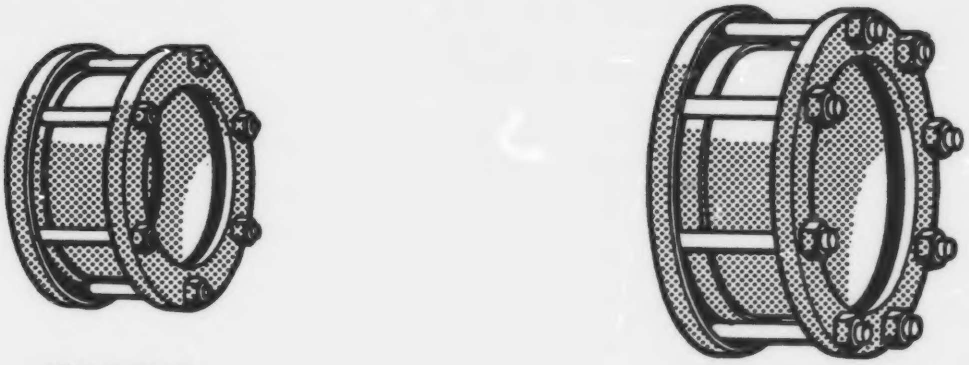
Plastic Pipe Flanges

Plastic pipe flanges will assemble with equivalent steel flanges, but require special "O" rings or gaskets. Do not use plastic pipe or flanges inside the power plant. Flanges are solvent or fusion welded to the pipe according to type.

Pipe Fittings

A wide range of fittings such as wye branches and reducers, is available for steel and plastic pipe. Branch connections or high pressure steel pipe should be made with preformed welding fittings. Sections of pipe containing wye branches, large bypass valve necks, etc. should be assembled as short units for ease of manipulation during welding. These can be flanged into the penstock later.

Flexible Pipe Couplings



8"ID STYLE
FOR 6"OD TO 8"OD

12"ID STYLE
FOR 10"OD TO 14"OD

FIG.4-46PIPE COUPLINGS

Pipe couplings consist of a sleeve, follower rings, flanges and resilient gaskets. Couplings can be used to join pipes without end preparation. This allows a certain flexibility at the connecting point. Couplings should not be confused with expansion joints, although they are often used for that application where the total movement per expansion joint is small. When installed, there is no way to ensure that couplings will not creep along the pipe. Painting a stripe of white paint close to the fitting on each side enables the joints to be checked periodically. Little change will be experienced unless the penstock is subjected to temperature extremes either during or after installation, or the penstock is subjected to water hammer.

High Pressure Couplings

Grooved couplings are often used in high pressure situations. Special end preparation of the pipe is required, and includes squaring the end of the pipe and rolling or cutting a special groove. This can be done at the pipe vendors. The coupling itself consists of two semi-circular halves and a special U-shaped gasket which spans the two pipe ends. The usual types are Victaulic and Dresser.

Expansion Joints

A number of different types of expansion joints are available. The main type is the concentric sleeve type, consisting of an inner pipe which can slide back and forth within an outer sleeve. A second type operates on the bellows principle either restrained or unrestrained. The restrained type is surrounded by a case limiting the distance by which it can be opened out. Either type is usually flanged into the pipeline where needed. This type of expansion joints is normally only used on high pressure steel penstocks.

When operating, the penstock will remain at a constant temperature, that of the water. However, during installation and draining above ground penstocks are subject to expansion and contraction in response to temperature changes. Provision must be made for this expansion and contraction, otherwise the pipe and pipe supports may be damaged.

For steel pipe, expansion couplers should be placed near thrust blocks having major changes in direction, and not more than 200 feet apart. As a rule, allow 1/4" to 3/8" movement for each expansion joint. Check with the manufacturers, as there is a number of different types. It is sometimes convenient to weld two to four 40 foot lengths of steel penstock together, coupling these 80-foot to 160-foot sections together with expansion joints. The pipe must be free to slide on pipe supports between thrust blocks.

On above ground plastic pipe runs, expansion joints may be necessary, depending upon the degree of restraint. For instance, if the pipe is installed in perfect alignment in concrete cradles, expansion joints will probably be necessary. Check with the pipe manufacturer as there is a trade-off involved between allowable longitudinal compressive and tensile stresses in the pipe, operating temperature, anticipated minimum winter temperatures and other factors. Normally, if the pipe is allowed to wander and is not rigidly clamped anywhere other than the thrust blocks expansion joints will not be necessary on above ground plastic penstocks.

Penstock can be kept reasonably cool by maintaining a small flow of water when the plant is shutdown for any reason. Final joints should be made in the evening when the pipe has cooled down.

Note: So-called "hot" soils, such as clay or soils containing sulphides or chlorides are characterized by low electrical resistance and can cause rapid corrosion on steel pipes. Special protective features may be necessary. Consult with specialists.

4.8 PLASTIC PENSTOCK

PVC and polyethylene pipes, described in detail below, have similar friction characteristics, and therefore can use the same nomographs and pipe loss tables. Figure 4-48 through Figure 4-55 list pipe sizes and characteristics for pvc and polyethylene pipe.

PVC Penstocks

A range of classes is available in PVC penstocks. SDR class, which is a trade designation, relates outside diameter to wall thickness. The pressure classes run from 63 psi to 315 psi, internal pressure. This pressure is the maximum static pressure for which the pipe is rated in order to give a reasonable working life (50 years). PVC pipe comes with an inherent safety factor of two times the pressure class number. Where pressure fluctuations are anticipated, such as in penstocks, manufacturers recommend that the class pressure rating be reduced by a service factor 0.66 times the class pressure.

Example: static pressure on penstock 105 psi.

$$\text{Pressure rating of pipe} = \frac{105}{0.66} = 159 \text{ psi}$$

Use class 160 pipe.

Note: With penstock velocities above 6 feet/second, water hammer becomes important and may have a very significant bearing on the pressure class of pipe selected, as well as the fatique life of the penstock.

Polyethylene Pipe (PE)

Polyethylene (PE) pipe is made in series numbers which equal the continuous static pressure the pipe will withstand and still have a reasonable working life (50 years or more). PE pipe has an inherent safety factor equal to two times the series working pressure rating, plus the normal operating pressure.

Similar to pvc, a service factor of 0.66 is used for penstocks. This service factor in combination with the low pipe velocity of five feet per second will provide adequate strength to resist moderate water hammer.

Steps for selecting a PVC or PE Pipe

The following are characteristics of a hypothetical site which is used throughout the remainder of Chapter 4.

(a) length of penstock = 1153 ft
(b) flow = 2.0 cfs
(c) assumed water velocity = 5 ft/sec.
(d) gross head = 279 ft, corresponding to 120 psi (approx.)
(psi = head x 0.433)
(e) list off valves, bends, etc. in the penstock

Profile Route

Draw a penstock profile on a large sheet of graph paper, using a horizontal scale of say, 1 inch = 100 feet and a vertical scale of, say 1 inch = 50 feet.

Divide the route into sections on roughly 25 psi pressure gradients, and establish the distances between these sections.

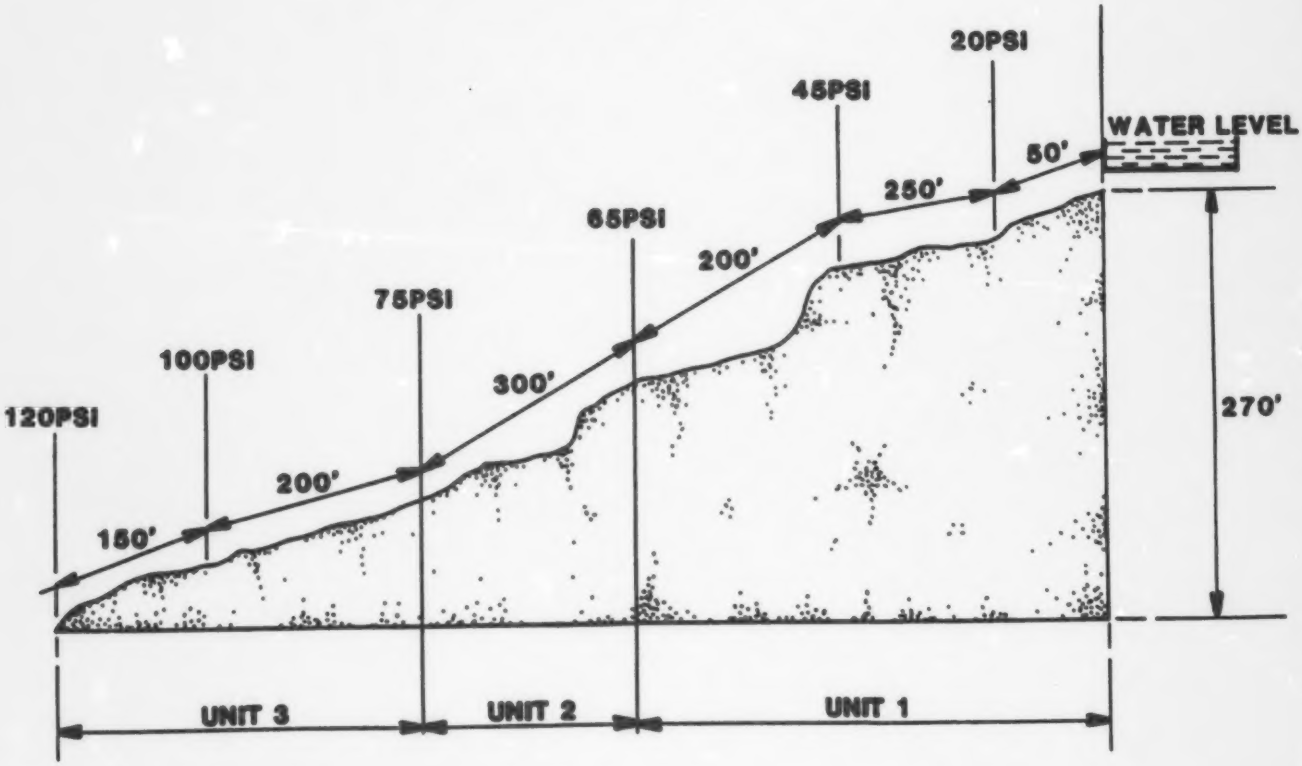

20PSI
45PSI
WATER LEVEL
50'
250'
65PSI
200'
75PSI
100PSI
300'
120PSI
270'
200'
150'
UNIT 3
UNIT 2
UNIT 1

FIG.4-47PENSTOCK PROFILE

Determine Pressure Class or Series

Determine necessary pressure class or series. In our example, the maximum penstock pressure is psi = 279 x 0.433 = 120.8 psi (use 120 psi)

$$\text{Pressure class} = \frac{120}{0.66} = 181.8 \text{ psi}$$

Use 200 psi class or series pipe.

Determine Pipe Size, Nomographic Method, Figure 4-45

For plastic pipe, total pipe losses should be about five percent. In our example of 1153 feet at 279 feet gross head, losses should be five percent of 279 or about 14 feet.

(a) Trial for pipe size: place a straightedge across Q scale and V scale using known values. In our example, use Q = 2 cfs and V = 5 ft/sec. (assumed).

This gives a pipe size of 8-1/2" inside diameter. Checking the pipe dimension tables, the nearest inside diameter at the required pressure rating, pvc pipe, is SDR 21, 8-inch nominal diameter, having an internal diameter of 7.75 inches. Try also one size large and one size smaller. In our case, six-inch and ten-inch.

(b) Trial for friction losses: place the straightedge across now established i.d. = 7.75" and Q = 2 ft^3/sec. Assume a C- facter for plastic pipe of 150. Losses for 1000 ft, for 8" SD21 is 15 ft/1000 ft. Similarly, for 10" SD21, losses are 4.75 ft/1000 ft. For 6" pipe, in this instance, losses are off the upper scale of the nomograph scale. Approximating from the steel pipe table, losses are 50 ft/1000 ft.

Available Choices

6" nominal SDR 21, 200 psi, 5.95 inches i.d.
8" nominal SDR 21, 200 psi, 7.75 inches i.d.
10" nominal SDR 21, 200 psi, 9.66 inches i.d.

Note: SDR 21 chosen on the basis of maximum pressure requirements.

Procedure, Plastic Pipe, Nomogram Method

For penstocks longer than 1500 times the internal diameter, no addition need be made for minor losses such as one caused by valves or bends*. These losses will amount to only a small fraction of the pipe head loss. In our example, which is roughly equal to or longer than 1500 times the internal diameter, we will add 25% to the head loss to provide some latitude for site conditions which may not be ideal. A friction factor of C-120 will be used.

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* Civil Engineering Handbook

Choices: 6", 8", or 10"

1. 6" pipe - loss/1000' = 50 feet

   Loss in 1153 feet = 1153 x 50/1000 = 57.6 feet
   Adding 25% of 57.6 = .25 x 57.6 + 57.6 = 72 feet
   Net head = 279 - 72 = 207 feet Net Head
   Velocity = 12 ft/sec. (too high)
   $KW = \frac{QHE}{11.81} = 25.8$ KW

2. 8" Pipe - loss/1000' = 15 feet

   Loss in 1153 feet = 1153 x 15/1000 = 22.5 feet
   Adding 25% of 22.5 = .25 x 22.5 + 22.5 = 28.1 feet
   Net head = 279 - 28 = 251 feet Net Head
   Velocity = 6 ft/sec. (good)
   KW = 31.3 KW

3. 10" pipe - loss/1000' = 4.75 feet

   Loss in 1153 feet = 1153 x 4.75/1000 = 5.47 feet
   Adding 25% of 5.47 = .25 x 5.47 + 5.47 = 6.84 feet
   Net head = 279 - 6.84 = 272.15 feet
   Velocity = 4 ft/sec. (uneconomic)
   KW = 33.9 KW

The gain in power using the 10" pipe is too small to warrant its use.

Note: for short penstocks or for velocities above 6-7 ft/sec, miscellaneous losses should be calculated:

$$HL = \frac{KV^2}{2g}$$

where HL = head loss in feet
K = a constant, (table below)
V = velocity in ft/sec
g = 32.2

Pipe projecting into reservoir	0.8
Sharp cornered intake	0.5
Slightly rounded intake	0.25
Bell mouth intake	0.05
Gate valve, fully open	0.2
Globe valve, fully open	10
45 degree elbow, short	0.4
22-1/2 degree elbow, short	0.25
11-1/4 degree elbow	0.15
90 degree elbow	0.9
Mitre joints, as above	

Head loss from items installed in the penstock are added to the penstock head loss to arrive at the total figure.

Refining the Design

The pipe thickness and hence cost can be reduced by determining the necessary pressure rating for head change over the run of pipe, then making the adjustments. Usually two or three sizes will suffice, and it is important not to reduce down to very light pipe at the top end, because there is the possibility of water hammer. The following table gives results from dividing the penstock into three units of varying pressure ratings.

Summary of Results

8" Plastic Pipe

Unit	PSI	Pipe PSI	Length Feet	Head Losses, Feet
1	98	SDR 100	500	5.75
2	113	SDR 125	300	3.3
3	181	SDR 200	350	7.75
Miscellaneous losses				4.2
Total penstock losses				21.0
Net head 279 - 21 =				258
KW				32.1

Note that head loss does not change appreciably, but significant cost savings can result from the use of lighter wall pipe in the upper part of the penstock.

Very little in the way of economy would result from installing the 6" pipe, intending to install another 6" pipe later on. Head conditions on the turbine would result which would alter its speed. At the very least, new belts and pulleys would be needed. One single 6" pipe would be very sensitive to water hammer on account of the high water velocity.

Other Refinements

The lower reaches of the penstock could be 8" I.D., and the upper reaches 10" I.D. pipe. This could be arranged to lower the head loss to about the mean value of 8" and 10" losses. Possibly new or good used lightwall steel pipe could also be used upstream.

Other Factors

1. Always change to steel pipe at the power plant thrust block. Plastic pipes should not be installed in the power plant.

2. If water offtakes are necessary along the penstock route for irrigation or other purposes, the offtakes should have only one shut-off valve and that should be at the penstock. Branch pipes which run for an appreciable distance to a valve or closed end can seriously magnify water hammer.

3. Avoid sudden changes in diameter, and use pre-formed reducers when necessary above the thrust block and cone reducers in the steel pipe below it.

4. In buried pipelines, a minimum wall thickness is often necessary. Check with the manufacturers.

   Note that pipe internal diameter decreases with increasing wall thickness. This is especially important when sizing plastic pipe. For instance, if you start off with 10" I.D. at the inlet, you may arrive at a much smaller diameter at the turbine because of pressure class increases down the penstock route. Pipeline losses will then be higher.

   At the time of writing, metric pipe is becoming available in sizes over eight inches.

Caution

There are many pipe standards in existence, and it is very easy to become confused between nominal pipe diameter and inside diameter when calculating losses. Always work from internal diameter, and make sure that any friction charts you use are based on internal diameter and not on so called "nominal pipe diameter". Friction charts are often laid out in U.S. gallons per minute. To convert cubic feet per second to U.S. gallons per minute, multiply by 7.48.

Manufacturer's Data

The manufacturer will recommend pipe sizes and series numbers together with installation requirements. They should be furnished with a copy of your penstock profile.

DIMENSIONS, WEIGHTS AND PRESSURE RATINGS OF PVC PIPE

	IMPERIAL						METRIC					
Schedule or S.D.R.	Nominal Pipe Size inches	Outside Diameter inches	Maximum Working Pressure PSI at 73°F	Minimum Wall Thickness inches	Average Inside Diameter inches	Weight of pipe per Ft (lbs)	Nominal Pipe Size (mm)	Outside Diameter (mm)	Maximum Working Pressure (kPa) at 23°C	Minimum Wall Thickness (mm)	Average Inside Diameter (mm)	Weight of pipe per (kg/m)
SCHD 40	1/2	.840	600	.109	.602	.16	12	21.3	4140	2.76	15.26	.238
SCHD 80			850	.147	.526	.21			5860	3.72	13.34	.313
SDR 21			200	.080	.660	.13			1380	2.02	16.74	193
SCHD 40	3/4	1.050	480	.113	.804	.22	20	26.70	3300	2.86	20.46	.327
SCHD 80			690	.154	.722	.28			4760	3.90	18.38	.417
SDR 21			200	.080	.870	.17			1380	2.02	22.14	253
SCHD 40	1	1.315	450	.133	1.029	.32	25	33.40	3100	3.38	26.14	476
SCHD 80			630	.179	.936	.41			4340	4.54	23.78	.610
SDR 21			200	.080	1.135	.21			1380	2.02	28.84	.313
SCHD 40	1 1/4	1.660	370	.141	1.360	.43	32	42.15	2550	3.56	34.53	.640
SCHD 80			520	.191	1.255	.57			3590	4.84	31.87	.848
SDR 21			200	.080	1.480	.27			1380	2.02	37.59	.402
SCHD 40	1 1/2	1.900	330	.145	1.590	.52	40	48.25	2280	3.68	40.37	.774
SCHD 80			470	.200	1.476	.68			3240	5.08	37.49	1.012
SDR 21			200	.090	1.700	.34			1380	2.28	43.17	.506
SDR 26			160	.080	1.720	.31			1100	2.02	43.69	.461
SCHD 40	2	2.375	280	.154	2.047	.69	50	60.35	1930	3.90	52.03	1.027
SCHD 80			400	.218	1.913	.94			2760	5.54	48.61	1.399
SDR 21			200	.113	2.129	.53			1380	2.86	54.11	.789
SDR 26			160	.091	2.173	.44			1100	2.30	55.23	.655
SCHD 40	2 1/2	2.875	300	.203	2.445	1.09	65	73.00	2070	5.16	62.08	1.622
SCHD 80			420	.276	2.290	1.44			2900	7.00	58.16	2.143
SDR 21			200	.137	2.581	.77			1380	3.48	65.54	1.146
SDR 26			160	.110	2.635	.63			1100	2.78	66.92	.938
SCHD 40	3	3.500	260	.216	3.042	1.44	75	88.90	1790	5.48	77.28	2.128
SCHD 80			370	.300	2.864	1.93			2550	7.62	72.74	2.872
SDR 21			200	.167	3.146	1.12			1380	4.24	79.92	1.667
SDR 26			160	.135	3.210	.93			1100	3.42	81.54	1.384
SDR 32.5			125	.108	3.264	.76			860	2.74	82.90	1.131
SDR 41			100	.085	3.310	.62			690	2.16	84.08	.923
SCHD 40	4	4.500	220	.237	3.998	2.03	100	114.30	1520	6.02	101.56	3.021
SCHD 80			320	.337	3.786	2.82			2210	8.56	96.16	4.197
SDR 21			200	.214	4.046	1.85			1380	5.44	102.76	2.753
SDR 26			160	.173	4.133	1.52			1100	4.38	105.00	2.262
SDR 32.5			125	.138	4.204	1.23			860	3.50	106.78	1.830
SDR 41			100	.110	4.260	1.00			690	2.78	108.22	1.488
SCHD 40	5	5.563	190	.258	5.016	2.76	125	141.30	1310	6.54	127.42	4.107
SCHD 80			290	.375	4.768	3.92			2000	9.52	121.12	5.834
SDR 21			200	.265	5.001	2.83			1380	6.72	127.04	4.212
SDR 26			160	.214	5.107	2.32			1100	5.44	129.74	3.453
SDR 32.5			125	.171	5.199	1.87			860	4.34	132.08	2.783
SDR 41			100	.136	5.271	1.51			690	3.44	133.90	2.247
SCHD 40	6	6.625	180	.280	6.031	3.58	150	168.30	1240	7.10	153.22	5.328
SCHD 80			280	.432	5.709	5.38			1930	10.96	145.04	8.006
SDR 21			200	.315	5.955	4.01			1380	8.02	151.28	5.968
SDR 26			160	.255	6.084	3.28			1100	6.48	154.56	4.881
SDR 32.5			125	.204	6 [illegible]	2.64			860	5.18	157.32	3.929
SDR 41			100	.161	6.281	2.12			690	4.12	159.56	3.155
SCHD 40	8	8.625	160	.322	7.941	5.40	200	219.05	1100	8.18	201.71	8.036
SCHD 80			250	.500	7.565	8.17			1720	12.70	192.13	12.158
SDR 21			200	.411	7.756	6.79			1380	10.40	196.99	10.105
SDR 26			160	.332	7.921	5.55			1100	8.42	201.79	8.259
SDR 32.5			125	.266	8.063	4.47			860	6.72	204.79	6.652
SDR 41			100	.210	8.180	3.57			690	5.32	207.77	5.313

	IMPERIAL						METRIC					
Schedule or S.D.R.	Nominal Pipe Size inches	Outside Diameter inches	Maximum Working Pressure PSI at 73°F	Minimum Wall Thickness inches	Average Inside Diameter inches	Weight of pipe per Ft. (lbs)	Nominal Pipe Size (mm)	Outside Diameter (mm)	Maximum Working Pressure (kPa) at 23°C	Minimum Wall Thickness (mm)	Average Inside Diameter (mm)	Weight of pipe per (kg/m)
SCHD 40	10	10.750	140	.365	9.976	7.64	250	273.05	970	9.26	253.41	11.370
SCHD 80			230	.593	9.493	12.12			1590	15.06	241.13	18.037
SDR 21			200	.512	9.667	10.54			1380	12.98	245.55	15.685
SDR 26			160	.413	9.874	8.60			1100	10.48	250.81	12.798
SDR 32.5			125	.331	10.048	6.95			860	8.40	255.23	10.343
SDR 41			100	.262	10.195	5.55			690	6.66	258.95	8.259
SCHD 40	12	12.750	130	.406	11.888	10.12	300	323.90	900	10.30	302.04	15.060
SCHD 80			230	.687	11.294	16.67			1590	17.44	286.92	24.808
SDR 21			200	.607	11.465	14.76			1380	15.38	291.28	21.965
SDR 26			160	.490	11.711	12.11			1100	12.44	297.52	18.022
SDR 32.5			125	.392	11.919	9.77			860	9.96	302.78	14.539
SDR 41			100	.311	12.091	7.81			690	7.90	307.16	11.623
SCHD 40	14	14.000	130	.438	13.072	11.96	350	355.60	900	11.13	332.03	17.80
SCHD 80			220	.750	12.412	19.96			1590	19.05	315.22	29.70
SDR 21			200	.665	12.590	17.85			1380	16.88	319.80	26.56
SDR 26			160	.538	12.859	14.60			1100	13.66	326.62	21.73
SDR 32.5			125	.431	13.100	11.61			860	10.70	332.78	17.28
SDR 41			100	.342	13.277	9.40			690	8.66	337.24	13.99
SCHD 40	16	16.000	130	.500	14.936	15.67	400	406.40	900	12.70	379.38	23.32
SCHD 80			220	.843	14.224	25.55			1590	21.41	361.29	38.02
SDR 21			200	.760	14.388	23.35			1380	19.30	365.48	34.75
SDR 26			160	.615	14.696	19.05			1100	15.62	373.28	28.35
SDR 32.5			125	.492	14.970	15.19			860	12.32	380.24	22.61
SDR 41			100	.391	15.172	12.29			690	9.90	385.38	18.29
SDR 21	18	18.000	200	.857	16.182	29.54	450	457.20	1380	21.72	411.14	43.96
SDR 26			160	.693	16.531	24.16			1100	17.60	419.88	35.95
SDR 32.5			125	.554	16.825	19.50			860	14.06	427.36	29.02
SDR 41			100	.440	17.065	15.63			690	11.14	433.46	23.26
SDR 21	20	20.000	200	.952	17.982	36.44	500	508.00	1380	24.12	456.86	54.23
SDR 26			160	.770	18.368	29.81			1100	19.56	466.54	44.36
SDR 32.5			125	.615	18.696	24.02			860	15.62	474.88	35.75
SDR 41			100	.489	18.963	19.25			690	12.42	481.66	28.65
SDR 21	24	24.000	200	1.143	21.576	52.49	600	609.60	1380	28.96	548.20	78.11
SDR 26			160	.924	22.041	42.95			1100	23.46	559.86	63.92
SDR 32.5			125	.740	22.431	34.70			860	18.80	569.74	51.64
SDR 41			100	.585	22.760	27.60			690	14.86	578.10	41.07

FOR OTHER SCEPTER PVC PIPING PRODUCTS SEE THE FOLLOWING:

- **4" (100 mm) to 27" (675 mm) PSM gasket joint sewer pipe, see brochure no. PSM-ENG-82**
- **1-1/2" (40 mm) to 24" (600 mm) Plas-tyton, IPS O.D. gasket joint pressure pipe, brochure no. PT-24-81**
- **4" (100 mm) to 12" (300 mm) Plas-tyton AWWA C-900, cast iron O.D. gasket joint water pipe, brochure no. C-900-1/84**

ADDITIONAL HELPFUL FORMULAS

Area of outside surface	(sq. ft./linear foot)	= $0.2618D$
Weight of pipe	(lbs/foot)	= $1.905t\,(D-t)$
Weight of water	(lbs/foot)	= $0.3405\,d^2$
Moment of inertia	(inches⁴)	= $0.0491\,(D^4-d^4)$
Section modulus	(inches³)	= $\dfrac{0.0982\,(D^4-d^4)}{D}$

Where: t = mean pipe wall thickness (inches)
D = outside diameter (inches)
d = inside diameter (inches)

NOTES

PVC is not recommended for compressed air or gas service.

For threaded systems reduce maximum working pressure by 50%

For services exceeding 73°F, see temperature correction chart, page 10.

FIG 4- 44

Sclairpipe polyethylene pipe • Straight Lengths

TABLE 1 DIMENSIONS IN MILLIMETRES

NOMINAL PIPE SIZE mm (in.)	Average Outside Diameter mm	SERIES 45			SERIES 60			SERIES 80			SERIES 100		
		Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m
75 (3)	89				90.1	4.1	1.1	77.5	5.3	1.4	74.9	6.6	1.7
100 (4)	114				104.6	4.5	1.6	101.5	6.0	2.1	98.6	7.4	2.5
150 (6)	168	157.4	5.1	2.6	154.0	6.7	3.4	149.6	8.9	4.4	145.3	10.9	5.4
200 (8)	219	205.0	6.6	4.5	200.6	8.7	5.8	194.8	11.5	7.5	189.2	14.1	9.1
250 (10)	252	235.5	7.5	5.8	230.4	9.9	7.6	223.9	13.1	9.8	217.4	16.1	11.9
315 (12)	316	296.4	9.5	9.2	290.0	12.5	12.0	281.7	16.5	15.5	273.6	20.3	18.8
355 (14)	356	333.9	10.7	11.6	326.7	14.1	15.2	317.3	18.6	19.7	308.2	22.9	23.9
400 (16)	402	375.9	12.0	15.1	367.6	15.9	19.7	356.9	20.9	25.5	346.3	25.8	31.0
450 (18)	452	422.7	13.5	19.1	413.4	17.9	24.9	401.2	23.5	32.3	389.4	29.0	39.2
500 (20)	502	469.5	15.0	23.6	459.1	19.9	30.7	445.6	26.1	39.8	432.5	32.2	48.4
560 (22)	562	525.6	16.8	29.5	514.0	22.2	38.5	498.9	29.3	49.9	484.2	36.1	60.
630 (24)	632	591.9	19.0	37.3	578.0	25.0	48.7	561.0	32.9	63.1	544.5	40.6	76.7
710 (28)	712	665.9	21.4	47.3	651.2	28.2	61.8	632.0	37.1	80.1	(613.4	45.8	97.4)
800 (32)	802	750.6	24.1	60.1	734.0	31.8	78.4	712.4	41.8	101.7	(691.4	51.6	123.7)
900 (36)	902	844.1	27.1	76.0	825.5	35.7	99.2	801.2	47.0	128.6			
1000 (40)	1002	937.6	30.1	93.8	916.9	39.7	122.4	(889.9	52.3	158.7)			
1050 (42)	1067	997.6	32.1	106.8	975.5	42.4	139.4	(946.7	55.8	180.8)			
1200 (48)	1204	1125.7	36.1	135.0	1100.8	47.7	176.2	(1068.5	62.7	228.6)			
1400 (55)	1405	1313.7	42.1	183.8	1284.8	55.6	239.9						
1600 (63)	1606	1501.8	48.1	240.0	(1468.7	63.5	313.3)						

NOTES:

(1) Reference Specifications: CGSB 41-GP-25M, ASTM F714-81.
(2) Design Stress: 75 mm – 4.3 MPa, 100 mm and above 5 MPa.
(3) 10 in. IPS and 12 in. IPS are available in all series numbers above.
(4) Pipe sizes with dimensions in brackets, as well as other sizes are available on special order.
(5) Series number represents recommended operating pressure (psig) for water at 23°C (73.4°F).
(6) Pipe, whose dimensions are printed in blue, is manufactured to IPS outside diameters, with nominal sizes determined by using the soft conversion of 25 mm = 1 inch.

FIG 4-50

SERIES 125			SERIES 145			SERIES 160			SERIES 200			SERIES 250		
Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m	Average Inside Diameter mm	Minimum Wall Thickness mm	Average Weight kg/m
71.7	8.1	2.1	69.3	9.2	2.3	67.5	10.1	2.5	62.9	12.3	2.9			
95.0	9.1	3.0	92.3	10.4	3.4	90.2	11.4	3.7	85.0	13.9	4.4	78.8	16.8	5.1
140.0	13.4	6.5	135.9	15.3	7.4	133.0	16.7	8.0	125.2	20.4	9.4	116.1	24.7	11.1
182.4	17.4	11.0	177.0	19.9	12.4	173.2	21.8	13.5	163.1	26.6	16.0	151.2	32.2	18.8
209.7	19.8	14.4	203.6	22.7	16.2	199.2	24.8	17.6	187.7	30.3	20.9	174.1	36.7	24.5
263.8	25.0	22.8	256.2	28.6	25.7	250.6	31.3	27.8	236.2	38.2	33.1	(219.1	46.3	38.9)
297.2	28.2	28.9	288.6	32.3	32.6	282.2	35.3	35.3	(266.0	43.0	42.0)			
333.6	31.7	37.5	323.7	36.3	42.4	316.4	39.7	45.8	(297.6	48.5	54.4)			
375.1	35.7	47.4	363.9	40.9	53.6	355.7	44.7	57.9	(334.6	54.5	68.8)			
416.5	39.7	58.5	404.1	45.4	66.1	(395.0	49.7	71.5)						
466.3	44.4	73.3	(452.4	50.9	82.8)									
524.4	50.0	92.7	(508.7	57.2	104.8)									
(590.7	56.3	117.7)												

FIG 4-51

Sclairpipe polyethylene pipe • Straight Lengths

TABLE 2 DIMENSIONS IN INCHES

NOMINAL PIPE SIZE in. (mm)	Average Outside Diameter in.	SERIES 45			SERIES 60			SERIES 80			SERIES 100		
		Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.
3 (75)	3.50				3.16	0.160	0.7	3.05	0.211	1.0	2.95	0.259	1.2
4 (100)	4.50				4.12	0.179	1.1	4.00	0.235	1.4	3.88	0.29[illegible]	[illegible]
6 (150)	6.63	6.20	0.199	1.8	6.06	0.263	2.3	5.89	0.346	3.0	5.72	0.427	3.6
8 (200)	8.63	8.07	0.260	3.0	7.90	0.343	3.9	7.67	0.451	5.0	7.45	0.556	6.1
10 (250)	9.90	9.27	0.296	3.9	9.07	0.391	5.1	8.81	0.514	6.6	8.56	0.635	8.0
12 (315)	12.46	11.67	0.373	6.2	11.42	0.493	8.0	11.09	0.648	10.4	10.77	0.800	12.7
14 (355)	14.04	13.14	0.420	7.8	12.86	0.555	10.2	12.49	0.730	13.2	12.13	0.901	16.1
16 (400)	15.83	14.80	0.474	10.2	14.47	0.625	13.2	14.05	0.823	17.2	13.64	1.015	20.9
18 (450)	17.80	16.64	0.533	12.8	16.27	0.704	16.7	15.80	0.926	21.7	15.33	1.142	26.4
20 (500)	19.76	18.48	0.592	15.8	18.08	0.782	20.6	17.54	1.029	26.7	17.03	1.269	32.5
22 (560)	22.13	20.69	0.663	19.8	20.24	0.876	25.9	19.64	1.152	33.5	19.06	1.422	40.8
24 (630)	24.88	23.27	0.746	25.1	22.76	0.985	32.7	22.09	1.296	42.4	21.44	1.599	51.6
28 (710)	28.03	26.22	0.841	31.8	25.64	1.110	41.5	24.88	1.461	53.8	(24.15	1.802	65.4)
32 (800)	31.59	29.55	0.948	40.4	28.90	1.251	52.7	28.05	1.646	68.3	(27.22	2.031	83.1)
36 (900)	35.53	33.23	1.066	51.1	32.50	1.407	66.7	31.54	1.852	86.4			
40 (1000)	39.47	36.91	1.184	63.0	36.10	1.564	82.2	(35.04	2.058	106.6)			
42 (1050)	42.00	39.27	1.264	71.8	38.40	1.669	93.7	(37.27	2.196	121.5)			
48 (1200)	47.38	44.32	1.421	90.7	43.34	1.876	118.4	(42.07	2.469	153.6)			
55 (1400)	55.30	51.72	1.658	123.5	50.58	2.189	161.2						
63 (1600)	63.21	59.13	1.895	161.3	(57.82	2.502	210.6)						

NOTES:

(1) Reference Specifications: CGSB 41-GP-25M, ASTM F714-81.

(2) Design Stress: 3" - 625 psi, 4" and above 725 psi.

(3) 10 in. IPS and 12 in. IPS are available in all series numbers above.

(4) Pipe Sizes with dimensions in brackets, as well as other sizes are available on special order.

(5) Series number represents recommended operating pressure (psig) for water at 23°C (73.4°F).

(6) Pipe whose dimensions are printed in blue is manufactured to IPS outside diameters with nominal sizes determined by using the soft conversion of 25 mm = 1 inch

Fig 4-52

SERIES 125			SERIES 145			SERIES 160			SERIES 200			SERIES 250		
Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.	Average Inside Diameter in.	Minimum Wall Thickness in.	Average Weight lb./ft.
2.82	0.318	1.4	2.73	0.364	1.6	2.66	0.397	1.7	2.48	0.483	2.0			
3.74	0.357	2.0	3.63	0.409	2.3	3.55	0.447	2.5	3.35	0.545	2.9	3.10	0.662	3.4
5.51	0.526	4.4	5.35	0.602	4.9	5.23	0.655	5.3	4.94	0.803	6.3	4.57	0.974	7.5
7.18	0.685	7.4	6.97	0.784	8.4	6.62	0.857	9.0	6.42	1.045	10.7	5.95	1.268	12.6
8.25	0.781	9.7	8.02	0.894	10.9	7.84	0.978	11.8	7.39	1.192	14.0	6.86	1.447	16.5
10.39	0.984	15.3	10.09	1.127	17.3	9.87	1.232	18.7	9.30	1.503	22.2	(8.62	1.823	26.1)
11.70	1.109	19.4	11.36	1.270	21.9	11.11	1.388	23.7	(10.47	1.693	28.2)			
13.13	1.249	25.2	12.74	1.431	28.5	12.46	1.564	30.8	(11.72	1.908	36.6)			
14.77	1.405	31.9	14.33	1.610	36.0	14.00	1.760	38.9	(13.17	2.146	46.2)			
16.40	1.562	39.3	15.91	1.789	44.4	(15.55	1.955	48.0)						
18.36	1.749	49.3	(17.81	2.003	55.7)									
20.64	1.968	62.3	(20.03	2.254	70.4)									
(23.26	2.217	79.1)												

FIG 4- 53

Sclairpipe Coiled Polyethylene Pipe

TABLE 3 ALL DIMENSIONS IN MILLIMETRES

Nominal Pipe Size mm	Average Outside Diameter mm	SERIES 100 Average Inside Diameter mm	SERIES 100 Minimum Wall Thickness mm	SERIES 100 Average Weight kg/m	SERIES 160 Average Inside Diameter mm	SERIES 160 Minimum Wall Thickness mm	SERIES 160 Average Weight kg/m
19	22				17.0	2.5	0.15
25	29				21.8	3.3	0.25
38	48	40.9	3.6	0.5	37.1	5.5	0.7
50	60	51.2	4.5	0.8	46.4	6.8	1.1

Note: Design Stress of these sizes is 4.3 MPa.

TABLE 4 ALL DIMENSIONS IN INCHES

Nominal Pipe Size in.	Average Outside Diameter in.	SERIES 100 Average Inside Diameter in.	SERIES 100 Minimum Wall Thickness in.	SERIES 100 Average Weight lb./ft.	SERIES 160 Average Inside Diameter in.	SERIES 160 Minimum Wall Thickness in.	SERIES 160 Average Weight lb./ft.
¾ CTS	0.875				0.67	0.099	0.10
1 CTS	1.125				0.86	0.128	0.17
1½ IPS	1.900	1.61	0.141	0.33	1.46	0.216	0.50
2 IPS	2.375	2.02	0.176	0.50	1.83	0.270	0.70

Note: Design Stress of these sizes is 625 psi.

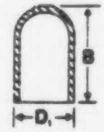
Fittings

The superior performance of SCLAIRPIPE results from the combination of pipe and fittings designed to work together as a complete system. The design integrity of these fittings has been demonstrated by years of proven service. Du Pont Canada believes that every element of your piping system should be carefully designed to work together to deliver superior performance in a cost-effective manner.

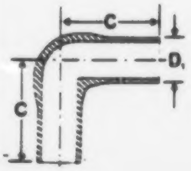
The SCLAIRPIPE system includes injection molded socket and plain end fittings, standard flange assemblies (consisting of polyethylene stub ends and metal flanges), and a complete range of fabricated polyethylene fittings including concentric reducers up to 1200 mm (48 in.) in diameter.

PLAIN END

END CAP



90° ELBOW



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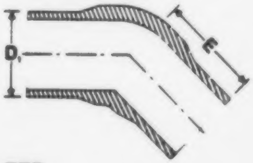

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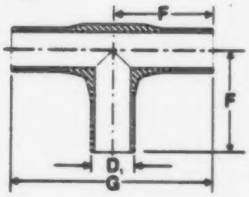
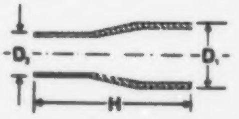
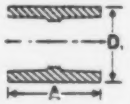


REDUCER



SOCKET FUSION

COUPLING



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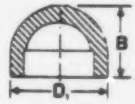
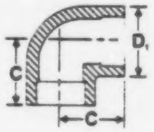


90° ELBOW



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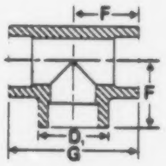

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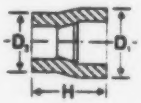
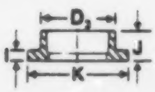


FLANGE ADAPTER



DU PONT CANADA INC.

FIG 4-54

NOMINAL PIPE SIZE In. (mm)	SERIES 125			SERIES 145			SERIES 160			SERIES 200			SERIES 250		
	Average Inside Diameter In.	Minimum Wall Thickness In.	Average Weight lb./ft.	Average Inside Diameter In.	Minimum Wall Thickness In.	Average Weight lb./ft.	Average Inside Diameter In.	Minimum Wall Thickness In.	Average Weight lb./ft.	Average Inside Diameter In.	Minimum Wall Thickness In.	Average Weight lb./ft.	Average Inside Diameter In.	Minimum Wall Thickness In.	Average Weight lb./ft.
3 (75)	2.82	0.318	1.4	2.73	0.364	1.6	2.66	0.397	1.7	2.48	0.483	2.0			
4 (100)	3.74	0.357	2.0	3.63	0.409	2.3	3.55	0.447	2.5	3.35	0.545	2.9	3.10	0.662	3.4
6 (150)	5.51	0.526	4.4	5.35	0.602	4.9	5.23	0.656	5.3	4.93	0.803	6.3	4.57	0.974	7.5
8 (200)	7.18	0.685	7.4	6.97	0.784	8.4	6.82	0.857	9.0	6.42	1.045	10.7	5.95	1.268	12.6
10 (250)	8.25	0.781	9.7	8.02	0.894	10.9	7.84	0.978	11.8	7.39	1.192	14.0	6.86	1.447	16.5
12 (315)	10.39	0.984	15.3	10.09	1.127	17.3	9.87	1.232	18.7	9.30	1.503	22.2	(8.62	1.823	26.1)
14 (355)	11.70	1.109	19.4	11.36	1.270	21.9	11.11	1.388	23.7	(10.47	1.693	28.2)			
16 (400)	13.13	1.249	25.2	12.74	1.431	28.5	12.46	1.564	30.8	(11.72	1.908	36.6)			
18 (450)	14.77	1.405	31.9	14.33	1.610	36.0	14.00	1.760	38.9	(13.17	2.146	46.2)			
20 (500)	16.40	1.562	39.3	15.91	1.789	44.4	(15.55	1.955	48.0)						
22 (560)	18.36	1.749	49.3	(17.81	2.003	55.7)									
24 (630)	20.64	1.968	62.3	(20.03	2.254	70.4)									
28 (710)	(23.26	2.217	79.1)												

FIG 4-55

4.9 STEEL PENSTOCKS

Procedures for Selecting a Steel Penstock

Pipe friction and hence head loss increases with age owing to the slow accumulation of rust and scale. It is customary to make an allowance for this by assuming a friction factor. Using the Hazen Williams friction factors, the following valves would be used:

New steel pipe,	C = 140	n = .010
10 to 15 year old steel pipe,	C = 120	n = .012
Older pipe or poor quality used pipe	C = 110	n = .013
Penstocks made up of cast iron, concrete and poor quality pipe,	C = 90	n = .015

The nomographs following are calculated out using the above C-values. It would be inadvisable to use C-140 unless the planned life of the installation is less than 10 years.

Normally, you would choose C=120 for new pipe 8" diameter or larger, or 110 for used pipe or pipes smaller than 8" diameter.

Note: The nomograms are in U.S. gallons. One Imperial gallon = 1.19 U.S. gallons. Also, 1 cubic foot = 6.25 Imperial gallons or 7.48 U.S. gallons.

Example: Steel Pipe Selection

Assume measured length to be 2100 feet from Chart 4-56. Determine the extra length of pipe.

Given: Q = 9 cfs
measured penstock length: 2100 feet
Gross head: 198 feet

From Chart 4-56 determine extra feet of pipe equivalent to allow for losses.

Say:	2 safe valves	5.8 x 2	11.6
	2-90° bends	18 x 2	36
	3-45° bends	9 x 3	27
			74.6

Equivalent length of pipeline = 2100 + 75 = 2175 feet.

(For approximationg pipe size, see Crane Co. table).

Work out gallons per minute, U.S. gpm.
= 9 x 60 x 7.48 = 4039 U.S. gpm

Examining the Table C-120, we wil work out three cases.

Case 1

12" pipe gives a head loss of 45 feet per 1000 feet.

For our case:

$$\frac{2175 \times 45}{1000} = 98 \text{ feet}$$

or approximately 33%. This is too high.

Case 2

14" pipe gives a head loss of 18 feet per 1000 feet.

For our case:

$$\frac{2175 \times 18}{1000} = 39 \text{ feet}$$

or approximately 19.7%. This would be acceptable for most small sites.

Case 3

16" pipe gives a head loss of 10 feet per 1000 feet.

For our case:

$$\frac{2175 \times 10}{1000} = 21.7 \text{ feet}$$

or approximately 11%. This would be used where energy must be maximized.

Available power:

Case 1

Net head: $198 - 98 = 100$ feet

KW: $\frac{100 \times 9}{11.81} = 76.2$ KW

Case 2

Net head: $198 - 39 = 159$ feet

KW: $\frac{159 \times 9}{11.81} = 121$ KW

Case 3

Net head: $198 - 21 = 177$ feet

KW: $\frac{177 \times 9}{11.81} = 134.8$ KW

Figure 4-56G-to J is the pipe friction table published by Crane Co. This is a widely used standard for industrial piping. It is based on Schedule 40 pipe and a friction factor of C-140. It should be used cautiously as it will give somewhat optimistic results on small steel penstocks.

Calculation of Necessary Pipe Wall Thickness; Steel Pipe

Having established the necessary pipe size, it is advisable to check that the wall thickness is adequate.

Hoop stress formula:

$$t = \frac{PD}{2S}$$

where t = wall thickness, inches
P = internal pressure, psi
D = outside diameter
S = design stress taken as 50% of yield strength, which is 15000 psi for ordinary steel pipe (higher strength pipe is available).

For our example, if 10 inch steel pipe were to be selected,

$$t = \frac{120 \times 10}{2 \times 1500} \quad 0.04''$$

A pipe this thin would be impractical for assembly, installation, and corrosion reasons. Traditionally, a minimum wall thickness of 1/4 inch was invariably selected; but in this example 3/16 wall would be adequate. In the case of buried pipe, the weight of the backfill and compaction forces often determine the minimum diameter rather than the internal pressure.

Increasing friction caused by corrosion over the long term does not significantly reduce the power output except in extreme cases. What happens is that a small incremental reduction in useful head takes place, which is accompanied by a proportional call for more water by the turbine in order to maintain output. This condition can normally be met, provided that the original water velocity was fairly moderate and if less than peak output is required.

Sources of Information

All pipe suppliers and maufacturers are a good source of information. Using your figures, they will select the best pipe on their range, and if requested to do so, will refer your enquiry to their factory applications engineer. By reason of legal liabilities, they will usually "suggest" pipe types. Not all small local pipe suppliers are technically qualified, and it is important when dealing with such firms to get factory or professional backup for the intended application. Municipal works department or city engineering departments may be willing to assist in the selection of pipe and installation practice, and may be a source of used equipment.

You may run into a certain amount of conflicting advice regarding installation requirements.

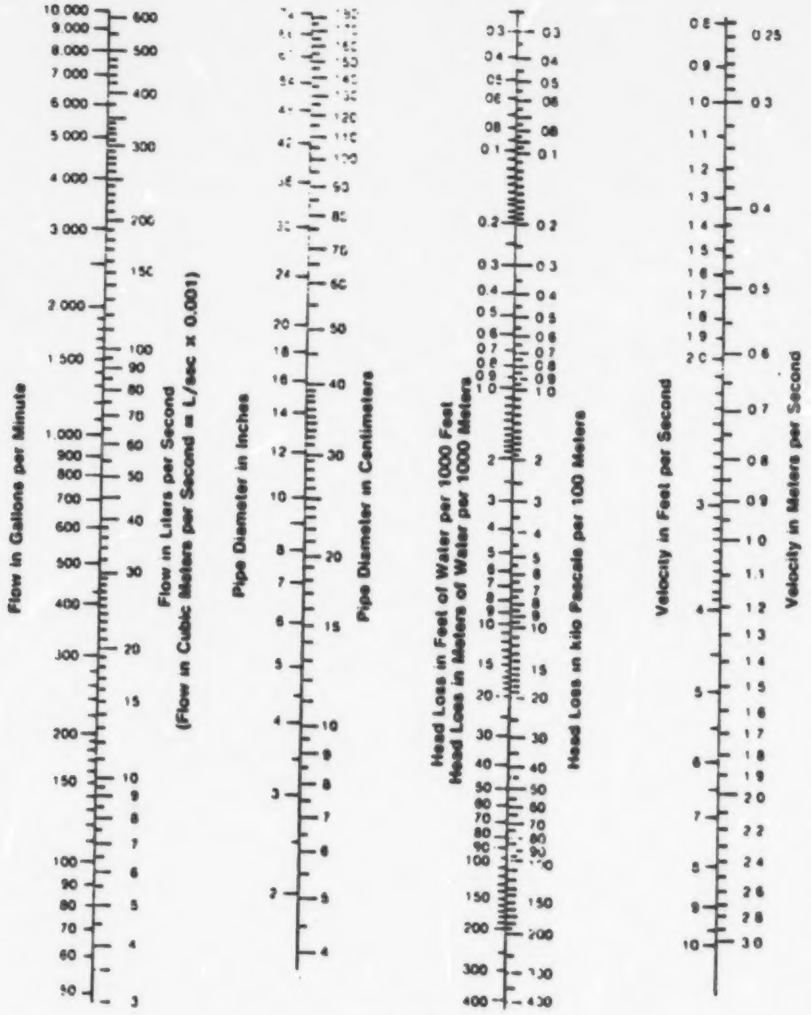
Pipes Installed Under Dams or Embankments

There are limits to the depth of backfill which can be placed on top of plastic pipes, and if this is over 8 feet or so, check with the pipe supplier or engineer. Steel pipe is seldom affected unless thin wall or large diameter.

Usually the cost and delivery of the pipe will determine the wall thickness and sometimes the diameter. Steel pipe is commonly stocked in 1/4" (.25), .203, .188, .156, .125; some wall thicknesses may be harder to come by. Avoid steel pipe which has been used to transport abrasive material such as sand, peat moss, etc. as the walls will be unevenly worn and impossible to rely on. Small increments in available power obtainable by going up in penstock size are usually uneconomical.

HAZEN-WILLIAMS FORMULA PIPE FLOW CHART

English/Metric Units

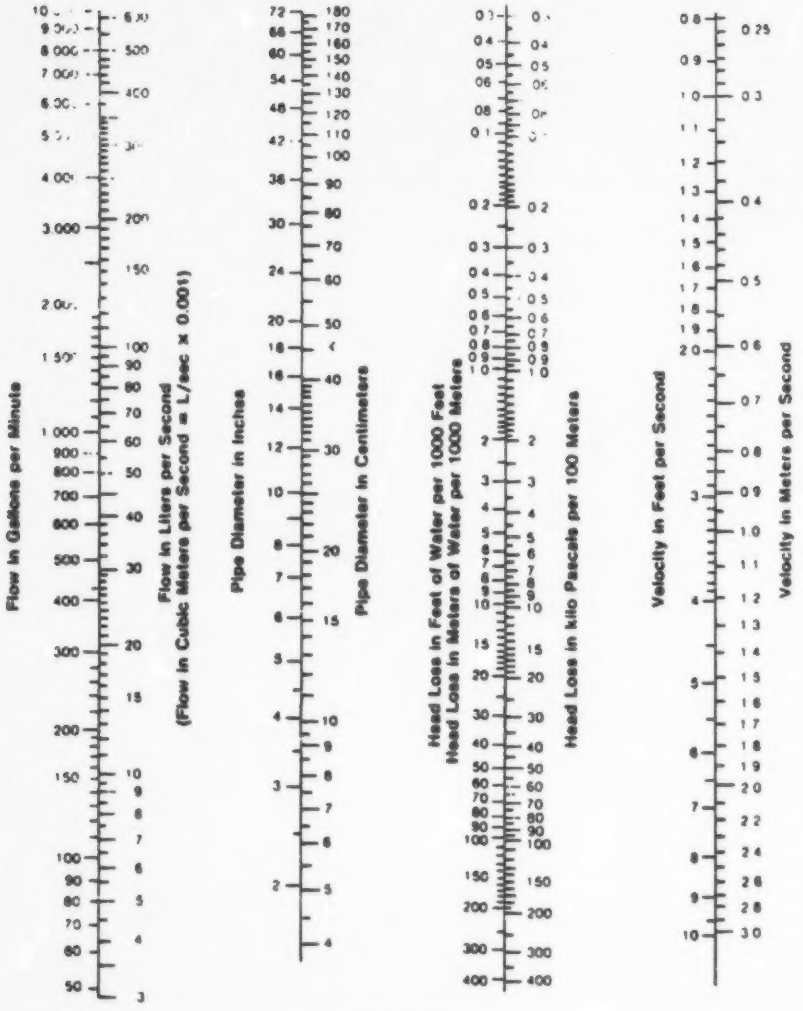

Flow in Gallons per Minute
Flow in Liters per Second
(Flow in Cubic Meters per Second = L/sec x 0.001)
Pipe Diameter in Inches
Pipe Diameter in Centimeters
Head Loss in Feet of Water per 1000 Feet
Head Loss in Meters of Water per 1000 Meters
Head Loss in kilo Pascals per 100 Meters
Velocity in Feet per Second
Velocity in Meters per Second

C=140

FIG 4-56A

HAZEN-WILLIAMS FORMULA PIPE FLOW CHART

English/Metric Units

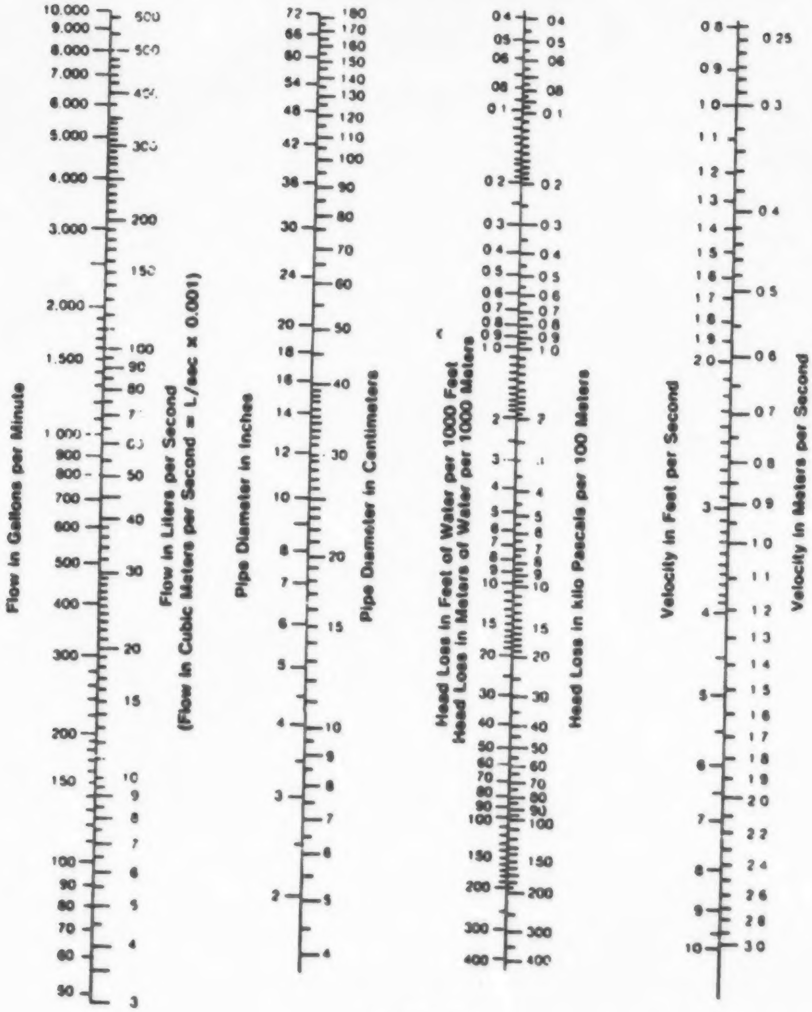


C=130

Fig 4-56B

HAZEN-WILLIAMS FORMULA PIPE FLOW CHART

English/Metric Units



C=110

Fig. 4-56C

HAZEN-WILLIAMS FORMULA PIPE FLOW CHART

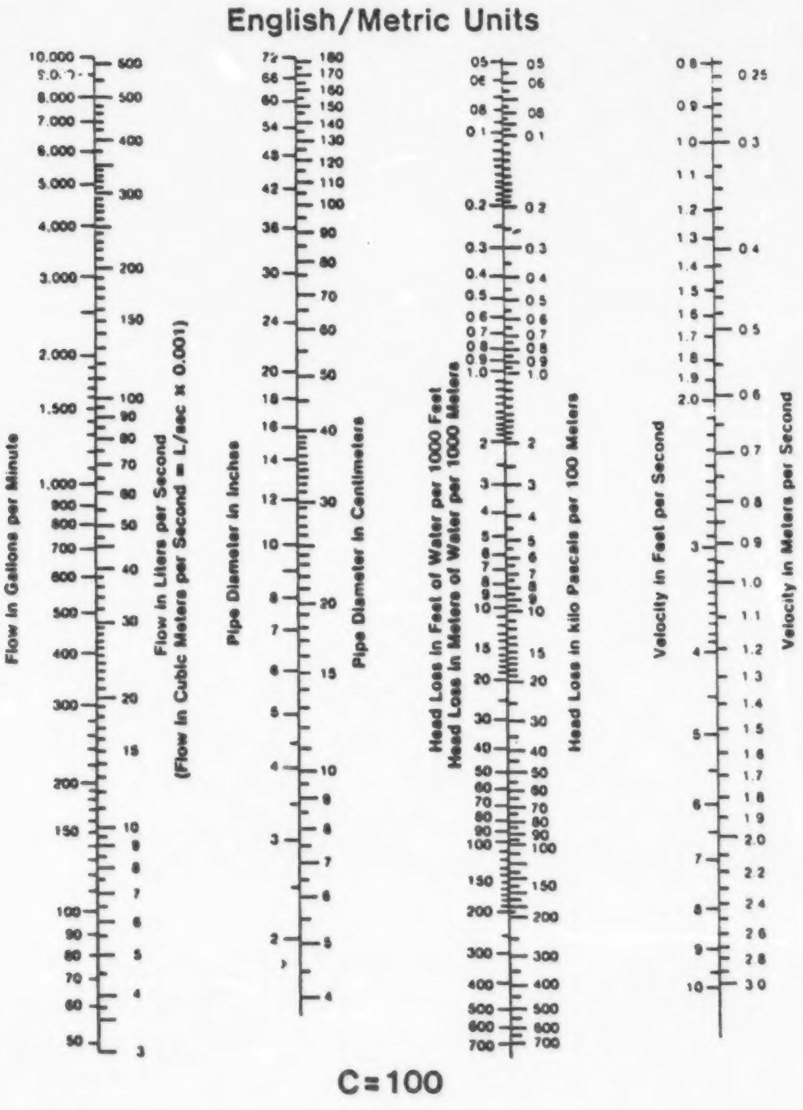
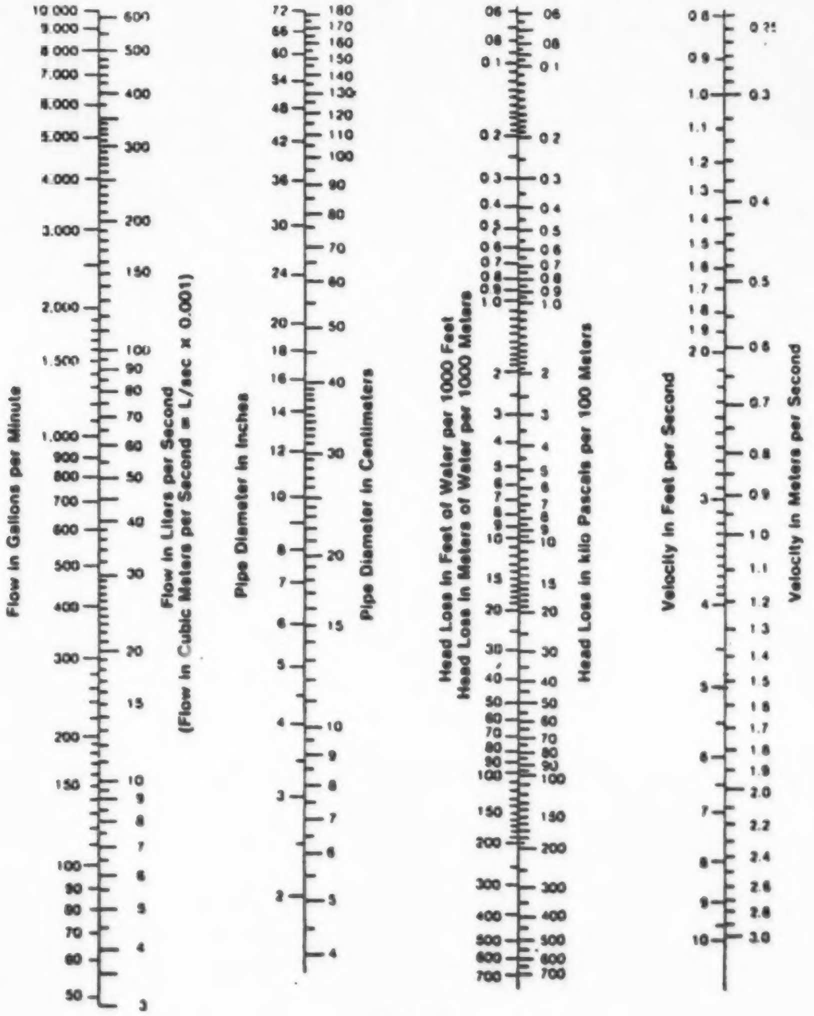


FIG. 4-56D

HAZEN-WILLIAMS FORMULA PIPE FLOW CHART

English/Metric Units



C=90

FIG. 4-56E

EQUIVALENT LENGTH OF PIPE FOR VARIOUS FITTINGS

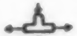
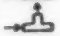
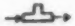
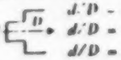
	For Nominal Pipe Diameter Shown, Equivalent Length of Pipe, Ft.																		
	½ In.	1 In.	1½ In.	2 In.	3 In.	4 In.	6 In.	8 In.	10 In.	12 In.	14 In.	16 In.	18 In.	20 In.	24 In.	30 In.	36 In.	42 In.	48 In.
Gate valve, open	0.3	0.6	0.9	1.2	1.7	2.3	3.5	4.5	5.8	6.9	8.0	9.0	10	12	14	17	20	23	27
Gate valve, ½ open	11	17	25	34	50	67	100	135	170	195	230	260	300	330	400	500	600	710	790
Globe valve, open	16	27	43	54	80	110	160	210	280	330	380	430	480	540	670	830	1,000	1,200	1,300
Angle valve, open	9.0	15	22	28	42	57	85	110	140	160	190	220	250	280	340	420	500	600	690
Check valve	3.9	6.5	11	14	19	25	40	51	66	77	90	110	120	130	160	200	230	280	320
Standard tee, 	3.4	5.7	9	12	17	22	34	44	57	67	75	89	100	110	130	170	200	240	270
Standard tee, 	3.4	5.7	9	12	17	22	34	44	57	67	75	89	100	110	130	170	200	240	270
Standard tee, 	1.1	1.7	2.7	3.5	5.1	6.9	11	14	18	20	23	27	30	34	42	52	61	72	82
90° Elbow, std.	1.5	2.7	4.4	5.4	8.1	11	17	21	26	31	37	42	48	52	63	80	98	110	130
90° Elbow, long radius	1.1	1.7	2.7	3.5	5.1	6.9	11	14	18	20	23	27	30	34	42	52	61	72	82
180° Return bend	3.6	6.1	10	13	18	23	36	48	60	72	83	100	110	125	150	180	220	260	300
45° Elbow	0.8	1.2	1.9	2.5	3.7	5.0	7.4	10	13	15	17	19	21	23	30	37	44	52	60
Ordinary entrance,	0.9	1.5	2.3	3.0	4.5	5.9	9.0	12	15	18	20	23	25	30	35	45	52	61	70
Sudden enlargement 																			
d/D = 1/4	1.5	2.7	4.4	5.4	8.1	11	17	21	26	31	37	42	48	52	63	80	98	110	130
d/D = 1/2	1.0	1.5	2.6	3.2	4.8	6.3	10	13	16	19	22	24	28	31	38	47	58	68	78
d/D = 3/4	0.3	0.6	0.9	1.2	1.7	2.3	3.5	4.5	5.8	6.9	8.0	9.0	10	12	14	17	20	23	27
Sudden contraction																			
d/D = 1/4	0.8	1.2	1.9	2.5	3.7	5.0	7.4	10	13	15	17	19	21	23	30	37	44	52	60
d/D = 1/2	0.6	0.9	1.5	1.9	2.8	3.7	5.7	7.5	9.7	12	13	15	17	18	22	27	33	40	45
d/D = 3/4	0.3	0.6	0.9	1.2	1.7	2.3	3.5	4.5	5.8	6.9	8.0	9.0	10	12	14	17	20	23	27

FIG. 4-56F.

Flow of Water Through Schedule 40 Steel Pipe

Discharge		Pressure Drop per 100 feet and Velocity in Schedule 40 Pipe for Water at 60 F.															
Gallons per Minute	Cubic Ft. per Second	Velocity Feet per Second	Press. Drop Lbs. per Sq. In	Velocity Feet per Second	Press. Drop Lbs. per Sq. In.	Velocity Feet per Second	Press. Drop Lbs. per Sq. In	Velocity Feet per Second	Press. Drop Lbs. per Sq. In	Velocity Feet per Second	Press. Drop Lbs. per Sq. In	Velocity Feet per Second	Press. Drop Lbs. per Sq. In	Velocity Feet per Second	Press. Drop Lbs. per Sq. In	Velocity Feet per Second	Press. Drop Lbs. per Sq. In
										4"							
25	0.05570																
30	0.06684																
35	0.07798									0.882	0.041						
40	0.08912									1.01	0.052						
45	0.1003									1.13	0.064						
												5"					
50	0.1114									1.26	0.076						
60	0.1337									1.51	0.107						
70	0.1560									1.76	0.143	1.12	0.047				
80	0.1782									2.02	0.180	1.28	0.060				
90	0.2005									2.27	0.224	1.44	0.074				
														6"			
100	0.2228									2.52	0.272	1.60	0.090	1.11	0.036		
125	0.2785									3.15	0.415	2.01	0.135	1.39	0.055		
150	0.3342									3.78	0.580	2.41	0.190	1.67	0.077		
175	0.3899									4.41	0.774	2.81	0.253	1.94	0.102		
200	0.4456									5.04	0.985	3.21	0.323	2.22	0.130		
																8"	
225	0.5013	...								5.67	1.23	3.61	0.401	2.50	0.162	1.44	0.043
250	0.557	...								6.30	1.46	4.01	0.495	2.78	0.195	1.60	0.051
275	0.6127	...	...							6.93	1.79	4.41	0.583	3.05	0.234	1.76	0.061
300	0.6684	...	...							7.56	2.11	4.81	0.683	3.33	0.275	1.92	0.072
325	0.7241	...	...	...						8.19	2.47	5.21	0.797	3.61	0.320	2.08	0.083
350	0.7798			...	...					8.82	2.84	5.62	0.919	3.89	0.367	2.24	0.095
375	0.8355			...	...					9.45	3.25	6.02	1.05	4.16	0.416	2.40	0.108
400	0.8912			...	...	...				10.08	3.68	6.42	1.19	4.44	0.471	2.56	0.121
425	0.9469			...	...	...				10.71	4.12	6.82	1.33	4.72	0.529	2.73	0.136
450	1.003			...	...	...				11.34	4.60	7.22	1.48	5.00	0.590	2.89	0.151
		10"															
475	1.059	1.93	0.054			...	...	...	...	11.97	5.12	7.62	1.64	5.27	0.653	3.04	0.166
500	1.114	2.03	0.059			...	...	...	...	12.60	5.65	8.02	1.81	5.55	0.720	3.21	0.182
550	1.225	2.24	0.071			...	...	...	...	13.85	6.79	8.82	2.17	6.11	0.861	3.53	0.219
600	1.337	2.44	0.083			...	...	...	...	15.12	8.04	9.63	2.55	6.66	1.02	3.85	0.258
650	1.448	2.64	0.097			...	...	...	...	...	...	10.43	2.98	7.22	1.18	4.17	0.301
				12"		14"											
700	1.560	2.85	0.112	2.01	0.047			...	...	...	...			7.78	1.35	4.49	0.343
750	1.671	3.05	0.127	2.15	0.054			...	...	...	...			8.33	1.55	4.81	0.392
800	1.782	3.25	0.143	2.29	0.061			...	...	...	...			8.88	1.75	5.13	0.443
850	1.894	3.46	0.160	2.44	0.068	2.02	0.042	...	...	...	...			9.44	1.96	5.45	0.497
900	2.005	3.66	0.179	2.58	0.075	2.13	0.047	...	...	...	...			9.99	2.18	5.77	0.554
								16"									
950	2.117	3.86	0.198	2.72	0.083	2.25	0.052			...	...					6.09	0.613
1 000	2.228	4.07	0.218	2.87	0.091	2.37	0.057			...	...					6.41	0.675
1 100	2.451	4.48	0.260	3.15	0.110	2.61	0.068			...	...					7.05	0.807
1 200	2.674	4.88	0.306	3.44	0.128	2.85	0.080	2.18	0.042	...	...					7.70	0.948
1 300	2.896	5.29	0.355	3.73	0.150	3.08	0.093	2.36	0.048	...	...					8.33	1.11
										18"							
1 400	3.119	5.70	0.409	4.01	0.171	3.32	0.107	2.54	0.055								
1 500	3.342	6.10	0.466	4.30	0.195	3.56	0.122	2.72	0.063								
1 600	3.565	6.51	0.527	4.59	0.219	3.79	0.138	2.90	0.071								
1 800	4.010	7.32	0.663	5.16	0.276	4.27	0.172	3.27	0.088	2.58	0.050						
2 000	4.456	8.14	0.808	5.73	0.339	4.74	0.209	3.63	0.107	2.87	0.060						
												20"		24"			
2 500	5.570	10.17	1.24	7.17	0.515	5.93	0.321	4.54	0.163	3.59	0.091					16.03	3.94
3 000	6.684	12.20	1.76	8.60	0.731	7.11	0.451	5.45	0.232	4.30	0.129	3.46	0.075			19.24	5.59
3 500	7.798	14.24	2.38	10.03	0.982	8.30	0.607	6.35	0.312	5.02	0.173	4.04	0.101			22.44	7.56
4 000	8.912	16.27	3.08	11.47	1.27	9.48	0.787	7.26	0.401	5.74	0.222	4.62	0.129	3.19	0.052	25.65	9.80
4 500	10.03	18.31	3.87	12.90	1.60	10.67	0.990	8.17	0.503	6.46	0.280	5.20	0.162	3.59	0.065	28.87	12.2
5 000	11.14	20.35	4.71	14.33	1.95	11.85	1.21	9.08	0.617	7.17	0.340	5.77	0.199	3.99	0.079	...	...
6 000	13.37	24.41	6.74	17.20	2.77	14.23	1.71	10.89	0.877	8.61	0.483	6.93	0.280	4.79	0.111	...	...
7 000	15.60	28.49	9.11	20.07	3.74	16.60	2.31	12.71	1.18	10.04	0.652	8.08	0.376	5.59	0.150	...	...
8 000	17.82	...	...	22.93	4.84	18.96	2.99	14.52	1.51	11.47	0.839	9.23	0.488	6.38	0.192	...	...
9 000	20.05	...	...	25.79	6.09	21.34	3.76	16.34	1.90	12.91	1.05	10.39	0.608	7.18	0.242	...	...
10 000	22.28	...	...	28.66	7.46	23.71	4.61	18.15	2.34	14.34	1.28	11.54	0.739	7.98	0.294	...	...
12 000	26.74	...	...	34.40	10.7	28.45	6.59	21.79	3.33	17.21	1.83	13.85	1.06	9.58	0.416	...	...
14 000	31.19	...	...	...	...	33.19	8.89	25.42	4.49	20.08	2.45	16.16	1.43	11.17	0.562	...	...
16 000	35.65	...	...	...	...	...	...	29.05	5.83	22.95	3.18	18.47	1.85	12.77	0.723	...	...
18 000	40.10	...	...	...	...	...	...	32.68	7.31	25.82	4.03	20.77	2.32	14.36	0.907	...	...
20 000	44.56	...	...	...	...	...	...	36.31	9.03	28.69	4.93	23.08	2.86	15.96	1.12	...	...

For pipe lengths other than 100 feet, the pressure drop is proportional to the length. Thus, for 50 feet of pipe, the pressure drop is approximately one-half the value given in the table . . . for 300 feet, three times the given value, etc.

Velocity is a function of the cross sectional flow area; thus, it is constant for a given flow rate and is independent of pipe length.

FIG 4-56 G.

PIPE FRICTION LOSS TABLE

Commercial Wrought Steel Pipe Data

(Per ASA B36.10-1950)

Nominal Pipe Size Inches	Outside Diameter Inches	Thickness Inches	Inside Diameter		Inside Diameter Functions (In Inches)				Transverse Internal Area	
			d Inches	D Feet	d^2	d^3	d^4	d^5	a Sq In	A Sq Ft
Standard Wall Pipe										
1/8	0.405	0.068	0.269	0.0224	0.0724	0.0195	0.00524	0.00141	0.057	0.00040
1/4	0.540	0.088	0.364	0.0303	0.1325	0.0482	0.01756	0.00639	0.104	0.00072
3/8	0.675	0.091	0.493	0.0411	0.2430	0.1198	0.05905	0.02912	0.191	0.00133
1/2	0.840	0.109	0.622	0.0518	0.3869	0.2406	0.1497	0.0931	0.304	0.00211
3/4	1.050	0.113	0.824	0.0687	0.679	0.5595	0.4610	0.3799	0.533	0.00371
1	1.315	0.133	1.049	0.0874	1.100	1.154	1.210	1.270	0.864	0.00600
1 1/4	1.660	0.140	1.380	0.1150	1.904	2.628	3.625	5.005	1.495	0.01040
1 1/2	1.900	0.145	1.610	0.1342	2.592	4.173	6.718	10.82	2.036	0.01414
2	2.375	0.154	2.067	0.1722	4.272	8.831	18.250	37.72	3.355	0.02330
2 1/2	2.875	0.203	2.469	0.2057	6.096	15.051	37.161	91.75	4.788	0.03322
3	3.500	0.216	3.068	0.2557	9.413	28.878	88.605	271.8	7.393	0.05130
3 1/2	4.000	0.226	3.548	0.2957	12.59	44.663	158.51	562.2	9.886	0.06870
4	4.500	0.237	4.026	0.3355	16.21	65.256	262.76	1058.	12.730	0.08840
5	5.563	0.258	5.047	0.4206	25.47	128.56	648.72	3275.	20.006	0.1390
6	6.625	0.280	6.065	0.5054	36.78	223.10	1352.8	8206.	28.891	0.2006
8	8.625	0.277	8.071	0.6725	65.14	525.75	4243.0	34248.	51.161	0.3553
	8.625S	0.322	7.981	0.6651	63.70	508.36	4057.7	32380.	50.027	0.3474
10	10.75	0.279	10.192	0.8493	103.88	1058.7	10789.	109876.	81.585	0.5666
	10.75	0.307	10.136	0.8446	102.74	1041.4	10555.	106987.	80.691	0.5604
	10.75S	0.365	10.020	0.8350	100.4	1006.0	10080.	101000.	78.855	0.5475
12	12.75	0.330	12.090	1.0075	146.17	1767.2	21366.	258300.	114.80	0.7972
	12.75S	0.375	12.000	1.000	144.0	1728.0	20736.	248800.	113.10	0.7854
Extra Strong Pipe										
1/8	0.405	0.095	0.215	0.0179	0.0462	0.00994	0.002134	0.000459	0.036	0.00025
1/4	0.540	0.119	0.302	0.0252	0.0912	0.0275	0.008317	0.002513	0.072	0.00050
3/8	0.675	0.126	0.423	0.0353	0.1789	0.0757	0.03201	0.01354	0.141	0.00098
1/2	0.840	0.147	0.546	0.0455	0.2981	0.1628	0.08886	0.04852	0.234	0.00163
3/4	1.050	0.154	0.742	0.0618	0.5506	0.4085	0.3032	0.2249	0.433	0.00300
1	1.315	0.179	0.957	0.0797	0.9158	0.8765	0.8387	0.8027	0.719	0.00499
1 1/4	1.660	0.191	1.278	0.1065	1.633	2.087	2.6667	3.409	1.283	0.00891
1 1/2	1.900	0.200	1.500	0.1250	2.250	3.375	5.062	7.594	1.767	0.01225
2	2.375	0.218	1.939	0.1616	3.760	7.290	14.136	27.41	2.953	0.02050
2 1/2	2.875	0.276	2.323	0.1936	5.396	12.536	29.117	67.64	4.238	0.02942
3	3.500	0.300	2.900	0.2417	8.410	24.389	70.728	205.1	6.605	0.04587
3 1/2	4.000	0.318	3.364	0.2803	11.32	38.069	128.14	430.8	8.888	0.06170
4	4.500	0.337	3.826	0.3188	14.64	56.006	214.33	819.8	11.497	0.07986
5	5.563	0.375	4.813	0.4011	23.16	111.49	536.6	2583.	18.194	0.1263
6	6.625	0.432	5.761	0.4801	33.19	191.20	1101.6	6346.	26.067	0.1810
8	8.625	0.500	7.625	0.6354	58.14	443.32	3380.3	25775.	45.663	0.3171
10	10.75	0.500	9.750	0.8125	95.06	926.86	9036.4	88110.	74.662	0.5185
12	12.75	0.500	11.750	0.9792	138.1	1622.2	19072.	223970.	108.434	0.7528
Double Extra Strong Pipe										
1/2	0.840	0.294	0.252	0.0210	0.0635	0.0160	0.004032	0.00102	0.050	0.00035
3/4	1.050	0.308	0.434	0.0362	0.1884	0.0817	0.03549	0.01540	0.148	0.00103
1	1.315	0.358	0.599	0.0499	0.3588	0.2149	0.1287	0.07711	0.282	0.00196
1 1/4	1.660	0.382	0.896	0.0747	0.8028	0.7193	0.6445	0.5775	0.630	0.00438
1 1/2	1.900	0.400	1.100	0.0917	1.210	1.331	1.4641	1.611	0.950	0.00660
2	2.375	0.436	1.503	0.1252	2.259	3.395	5.1031	7.670	1.774	0.01232
2 1/2	2.875	0.552	1.771	0.1476	3.136	5.554	9.8345	17.42	2.464	0.01710
3	3.500	0.600	2.300	0.1917	5.290	12.167	27.984	64.36	4.155	0.02885
3 1/2	4.000	0.636	2.728	0.2273	7.442	20.302	55.383	151.1	5.845	0.04059
4	4.500	0.674	3.152	0.2627	9.935	31.315	98.704	311.1	7.803	0.05419
5	5.563	0.750	4.063	0.3386	16.51	67.072	272.58	1107.	12.966	0.09006
6	6.625	0.864	4.897	0.4081	23.98	117.43	575.04	2816.	18.835	0.1308
8	8.625	0.875	6.875	0.5729	47.27	324.95	2234.4	15360.	37.122	0.2578

FIG 4-56H

Commercial Wrought Steel Pipe Data

Schedule Wall Thickness—Per ASA B36.10-1950

	Nominal Pipe Size	Outside Diameter	Thickness	Inside Diameter		Inside Diameter Functions (In Inches)			
				d	D				
	Inches	Inches	Inches	Inches	Feet	d^2	d^3	d^4	d^5
Schedule 10	14	14	0.250	13.5	1.125	182.25	2460.4	33215.	448400.
	16	16	0.250	15.5	1.291	240.25	3723.9	57720.	894660.
	18	18	0.250	17.5	1.4583	306.25	5359.4	93789.	1641309.
	20	20	0.250	19.5	1.625	380.25	7414.9	144590.	2819500.
	24	24	0.250	23.5	1.958	552.25	12977.	304980.	7167030.
	30	30	0.312	29.376	2.448	862.95	25350.	744288.	21864218.
Schedule 20	8	8.625	0.250	8.125	0.6771	66.02	536.38	4359.3	35409.
	10	10.75	0.250	10.25	0.8542	105.06	1076.9	11038.	113141.
	12	12.75	0.250	12.25	1.021	150.06	1838.3	22518.	275855.
	14	14	0.312	13.376	1.111	178.92	2393.2	32012.	428185.
	16	16	0.312	15.376	1.281	236.42	3635.2	55894.	859442.
	18	18	0.312	17.376	1.448	301.92	5246.3	91156.	1583978.
	20	20	0.375	19.250	1.604	370.56	7133.3	137317.	2643352.
	24	24	0.375	23.25	1.937	540.56	12568.	292205.	6793832.
	30	30	0.500	29.00	2.417	841.0	24389.	707281.	20511149.
Schedule 30	8	8.625	0.277	8.071	0.6726	65.14	525.75	4243.2	34248.
	10	10.75	0.307	10.136	0.8447	102.74	1041.4	10555.	106987.
	12	12.75	0.330	12.09	1.0075	146.17	1767.2	21366.	258304.
	14	14	0.375	13.25	1.1042	175.56	2326.2	30821.	408394.
	16	16	0.375	15.25	1.2708	232.56	3546.6	54084.	824801.
	18	18	0.438	17.124	1.4270	293.23	5021.3	85984.	1472397.
	20	20	0.500	19.00	1.5833	361.00	6859.0	130321.	2476099.
	24	24	0.562	22.876	1.9063	523.31	11971.	273853.	6264703.
	30	30	0.625	28.75	2.3958	826.56	23764.	683201.	19642160.
Schedule 40	⅛	0.405	0.068	0.269	0.0224	0.0724	0.0195	0.005242	0.00141
	¼	0.540	0.088	0.364	0.0303	0.1325	0.0482	0.01756	0.00639
	⅜	0.675	0.091	0.493	0.0411	0.2430	0.1198	0.05905	0.02912
	½	0.840	0.109	0.622	0.0518	0.3869	0.2406	0.1497	0.09310
	¾	1.050	0.113	0.824	0.0687	0.679	0.5595	0.4610	0.3799
	1	1.315	0.133	1.049	0.0874	1.100	1.154	1.210	1.270
	1¼	1.660	0.140	1.380	0.1150	1.904	2.628	3.625	5.005
	1½	1.900	0.145	1.610	0.1342	2.592	4.173	6.718	10.82
	2	2.375	0.154	2.067	0.1722	4.272	8.831	18.250	37.72
	2½	2.875	0.203	2.469	0.2057	6.096	15.051	37.161	91.75
	3	3.500	0.216	3.068	0.2557	9.413	28.878	88.605	271.8
	3½	4.000	0.226	3.548	0.2957	12.59	44.663	158.51	562.2
	4	4.500	0.237	4.026	0.3355	16.21	65.256	262.76	1058.
	5	5.563	0.258	5.047	0.4206	25.47	128.56	648.72	3275.
	6	6.625	0.280	6.065	0.5054	36.78	223.10	1352.8	8206.
	8	8.625	0.322	7.981	0.6651	63.70	508.36	4057.7	32380.
	10	10.75	0.365	10.02	0.8350	100.4	1006.0	10080.	101000.
	12	12.75	0.406	11.938	0.9965	142.5	1701.3	20306.	242470.
	14	14.0	0.438	13.124	1.0937	172.24	2260.5	29666.	389340.
	16	16.0	0.500	15.000	1.250	225.0	3375.0	50625.	759375.
	18	18.0	0.562	16.876	1.4063	284.8	4806.3	81111.	1368820.
	20	20.0	0.593	18.814	1.5678	354.0	6659.5	125320.	2357244.
	24	24.0	0.687	22.626	1.8855	511.9	11583.	262040.	5929784.
Schedule 60	8	8.625	0.406	7.813	0.6511	61.04	476.93	3725.9	29113.
	10	10.75	0.500	9.750	0.8125	95.06	926.86	9036.4	88110.
	12	12.75	0.562	11.626	0.9688	135.16	1571.4	18268.	212399.
	14	14.0	0.593	12.814	1.0678	164.20	2104.0	26962.	345480.
	16	16.0	0.656	14.688	1.2240	215.74	3168.8	46544.	683618.
	18	18.0	0.750	16.500	1.3750	272.25	4492.1	74120.	1222982.
	20	20.0	0.812	18.376	1.5313	337.68	6205.2	114028.	2095342.
	24	24.0	0.968	22.064	1.8387	486.82	10741.	236994.	5229036.
Schedule 80	⅛	0.405	0.095	0.215	0.0179	0.0462	0.00994	0.002134	0.000459
	¼	0.540	0.119	0.302	0.0252	0.0912	0.0275	0.008317	0.002513
	⅜	0.675	0.126	0.423	0.0353	0.1789	0.0757	0.03200	0.01354
	½	0.840	0.147	0.546	0.0455	0.2981	0.1628	0.08886	0.04852
	¾	1.050	0.154	0.742	0.0618	0.5506	0.4085	0.3032	0.2249
	1	1.315	0.179	0.957	0.0797	0.9158	0.8765	0.8387	0.8027
	1¼	1.660	0.191	1.278	0.1065	1.633	2.087	2.6467	3.409

FIG 4-56 I

Commercial Wrought Steel Pipe Data

Schedule Wall Thickness—Per ASA B36.10-1950

Schedule	Nominal Pipe Size Inches	Outside Diameter Inches	Thickness Inches	Inside Diameter d Inches	Inside Diameter D Feet	Inside Diameter Functions (In Inches) d^2	d^3	d^4	d^5	Transverse Internal Area a Sq In.	Transverse Internal Area A Sq Ft.
Schedule 80—cont.	1½	1.900	0.200	1.500	0.1250	2.250	3.375	5.062	7.594	1.767	0.01225
	2	2.375	0.218	1.939	0.1616	3.760	7.290	14.136	27.41	2.953	0.02050
	2½	2.875	0.276	2.323	0.1936	5.396	12.536	29.117	67.64	4.238	0.02942
	3	3.5	0.300	2.900	0.2417	8.410	24.389	70.728	205.1	6.605	0.04587
	3½	4.0	0.318	3.364	0.2803	11.32	38.069	128.14	430.8	8.888	0.06170
	4	4.5	0.337	3.826	0.3188	14.64	56.006	214.33	819.8	11.497	0.07986
	5	5.563	0.375	4.813	0.4011	23.16	111.49	536.38	2583.	18.194	0.1263
	6	6.625	0.432	5.761	0.4801	33.19	191.20	1101.6	6346.	26.067	0.1810
	8	8.625	0.500	7.625	0.6354	58.14	443.32	3380.3	25775.	45.663	0.3171
	10	10.75	0.593	9.564	0.7970	91.47	874.82	8366.8	80020.	71.84	0.4989
	12	12.75	0.687	11.376	0.9480	129.41	1472.2	16747.	190523.	101.64	0.7058
	14	14.0	0.750	12.500	1.0417	156.25	1953.1	24414.	305176.	122.72	0.8522
	16	16.0	0.843	14.314	1.1928	204.89	2932.8	41980.	600904.	160.92	1.1175
	18	18.0	0.937	16.126	1.3438	260.05	4193.5	67626.	1090518.	204.24	1.4183
	20	20.0	1.031	17.938	1.4948	321.77	5771.9	103536.	1857248.	252.72	1.7550
	24	24.0	1.218	21.564	1.7970	465.01	10027.	216234.	4662798.	365.22	2.5362
Schedule 100	8	8.625	0.593	7.439	0.6199	55.34	411.66	3062.	22781.	43.46	0.3018
	10	10.75	0.718	9.314	0.7762	86.75	807.99	7526.	69357.	68.13	0.4732
	12	12.75	0.843	11.064	0.9220	122.41	1354.4	14985.	165791.	96.14	0.6677
	14	14.0	0.937	12.126	1.0105	147.04	1783.0	21621.	262173.	115.49	0.8020
	16	16.0	1.031	13.938	1.1615	194.27	2707.7	37740.	526020.	152.58	1.0596
	18	18.0	1.156	15.688	1.3057	246.11	3861.0	60572.	950250.	193.30	1.3423
	20	20.0	1.281	17.438	1.4532	304.08	5302.6	92467.	1612438.	238.83	1.6585
	24	24.0	1.531	20.938	1.7448	438.40	9179.2	192195.	4024179.	344.32	2.3911
Schedule 120	4	4.50	0.438	3.624	0.302	13.133	47.595	172.49	625.1	10.315	0.07163
	5	5.563	0.500	4.563	0.3802	20.82	95.006	433.5	1978.	16.35	0.1136
	6	6.625	0.562	5.501	0.4584	30.26	166.47	915.7	5037.	23.77	0.1650
	8	8.625	0.718	7.189	0.5991	51.68	371.54	2671.	19202.	40.59	0.2819
	10	10.75	0.843	9.064	0.7553	82.16	744.66	6750.	61179.	64.53	0.4481
	12	12.75	1.000	10.750	0.8959	115.56	1242.3	13355.	143563.	90.76	0.6303
	14	14.0	1.093	11.814	0.9845	139.57	1648.9	19480.	230137.	109.62	0.7612
	16	16.0	1.218	13.564	1.1303	183.98	2495.5	33849.	459133.	144.50	1.0035
	18	18.0	1.375	15.250	1.2708	232.56	3546.6	54086.	824804.	182.66	1.2684
	20	20.0	1.500	17.000	1.4166	289.00	4913.0	83521.	1419857.	226.98	1.5762
	24	24.0	1.812	20.376	1.6980	415.18	8459.7	172375.	3512313.	326.08	2.2645
Schedule 140	8	8.625	0.812	7.001	0.5834	49.01	343.15	2402.	16819.	38.50	0.2673
	10	10.75	1.000	8.750	0.7292	76.56	669.92	5862.	51291.	60.13	0.4176
	12	12.75	1.125	10.500	0.8750	110.25	1157.6	12155.	127628.	86.59	0.6013
	14	14.0	1.250	11.500	0.9583	132.25	1520.9	17490.	201136.	103.87	0.7213
	16	16.0	1.438	13.124	1.0937	172.24	2260.5	29666.	389340.	135.28	0.9394
	18	18.0	1.562	14.876	1.2396	221.30	3292.0	48972.	728502.	173.80	1.2070
	20	20.0	1.750	16.5	1.3750	272.25	4492.1	74120.	1222981.	213.82	1.4849
	24	24.0	2.062	19.876	1.6563	395.06	7852.1	156069.	3102022.	310.28	2.1547
Schedule 160	½	0.840	0.187	0.466	0.0388	0.2172	0.1012	0.04716	0.02197	0.1706	0.00118
	¾	1.050	0.218	0.614	0.0512	0.3770	0.2315	0.1421	0.08726	0.2961	0.00206
	1	1.315	0.250	0.815	0.0679	0.6642	0.5413	0.4412	0.3596	0.5217	0.00362
	1¼	1.660	0.250	1.160	0.0966	1.346	1.561	1.811	2.100	1.057	0.00734
	1½	1.900	0.281	1.338	0.1115	1.790	2.395	3.205	4.288	1.406	0.00976
	2	2.375	0.343	1.689	0.1407	2.853	4.818	8.138	13.74	2.241	0.01556
	2½	2.875	0.375	2.125	0.1771	4.516	9.596	20.39	43.33	3.546	0.02463
	3	3.50	0.438	2.624	0.2187	6.885	18.067	47.41	124.4	5.408	0.03755
	4	4.50	0.531	3.438	0.2865	11.82	40.637	139.7	480.3	9.283	0.06447
	5	5.563	0.625	4.313	0.3594	18.60	80.230	346.0	1492.	14.61	0.1015
	6	6.625	0.718	5.189	0.4324	26.93	139.72	725.0	3762.	21.15	0.1469
	8	8.625	0.906	6.813	0.5677	46.42	316.24	2155.	14679.	36.46	0.2532
	10	10.75	1.125	8.500	0.7083	72.25	614.12	5220.	44371.	56.75	0.3941
	12	12.75	1.312	10.126	0.8438	102.54	1038.3	10514.	106461.	80.53	0.5592
	14	14.0	1.406	11.188	0.9323	125.17	1400.4	15668.	175292.	98.31	0.6827
	16	16.0	1.593	12.814	1.0678	164.20	2104.0	26961.	345482.	128.96	0.8956
	18	18.0	1.781	14.438	1.2032	208.45	3009.7	43454.	627387.	163.72	1.1369
	20	20.0	1.968	16.064	1.3387	258.05	4145.3	56590.	1069715.	202.67	1.4074
	24	24.0	2.343	19.314	1.6095	373.03	7204.7	139152.	2687582.	292.98	2.034

FIG 4-56 J

Dimensions of Welded and Seamless Steel Pipe

Nominal Diameter	Schedule	Outside Diameter	Wall Thickness	Internal Diameter	Internal Area	Internal Diameter	Internal Area
Inches		Inches	Inches	Inches	Square Inches	Feet	Square Feet
5	40 (S)	5.563	0.258	5.047	20.01	0.4206	0.1389
	80 (X)		0.375	4.813	18.19	0.4011	0.1263
	120		0.500	4.563	16.35	0.3803	0.1136
	160		0.625	4.313	14.61	0.3594	0.1015
	(XX)		0.750	4.063	12.97	0.3386	0.09004
6	40 (S)	6.625	0.280	6.065	28.89	0.5054	0.2006
	80 (X)		0.432	5.761	26.07	0.4801	0.1810
	120		0.562	5.501	23.77	0.4584	0.1650
	160		0.719	5.187	21.13	0.4323	0.1467
	(XX)		0.864	4.897	18.83	0.4081	0.1308
8	20	8.625	0.250	8.125	51.85	0.6771	0.3601
	30		0.277	8.071	51.16	0.6726	0.3553
	40 (S)		0.322	7.981	50.03	0.6651	0.3474
	60		0.406	7.813	47.94	0.6511	0.3329
	80 (X)		0.500	7.625	45.66	0.6354	0.3171
	100		0.594	7.437	43.44	0.6198	0.3017
	120		0.719	7.187	40.57	0.5989	0.2817
	140		0.812	7.001	38.50	0.5834	0.2673
	(XX)		0.875	6.875	37.12	0.5729	0.2578
	160		0.906	6.813	36.46	0.5678	0.2532
10	20	10.75	0.250	10.250	82.52	0.85417	0.5730
	30		0.307	10.136	80.69	0.84467	0.5604
	40 (S)		0.365	10.020	78.85	0.83500	0.5476
	60 (X)		0.500	9.750	74.66	0.8125	0.5185
	80		0.594	9.562	71.81	0.7968	0.4987
	100		0.719	9.312	68.11	0.7760	0.4730
	120		0.844	9.062	64.50	0.7552	0.4479
	140 (XX)		1.000	8.750	60.13	0.7292	0.4176
	160		1.125	8.500	56.75	0.7083	0.3941
12	20	12.75	0.250	12.250	117.86	1.0208	0.8185
	30		0.330	12.090	114.80	1.0075	0.7972
	(S)		0.375	12.000	113.10	1.0000	0.7854
	40		0.406	11.938	111.93	0.99483	0.7773
	(X)		0.500	11.750	108.43	0.97917	0.7530
	60		0.562	11.626	106.16	0.96883	0.7372
	80		0.688	11.374	101.61	0.94783	0.7056
	100		0.844	11.062	96.11	0.92183	0.6674
	120 (XX)		1.000	10.750	90.76	0.89583	0.6303
	140		1.125	10.500	86.59	0.87500	0.6013
	160		1.312	10.126	80.53	0.84383	0.5592
14 OD	10	14.00	0.250	13.500	143.14	1.1250	0.9940
	20		0.312	13.376	140.52	1.1147	0.9758
	30 (S)		0.375	13.250	137.89	1.1042	0.9575
	40		0.438	13.124	135.28	1.0937	0.9394
	(X)		0.500	13.000	132.67	1.0833	0.9213
	60		0.594	12.812	128.92	1.0677	0.8953
	80		0.750	12.500	122.72	1.0417	0.8522
	100		0.938	12.124	115.45	1.0104	0.8017
	120		1.094	11.812	109.58	0.98433	0.7610
	140		1.250	11.500	103.87	0.95833	0.7213
	160		1.406	11.188	98.31	0.93233	0.6827
16 OD	10	16.00	0.250	15.500	188.69	1.2917	1.3104
	20		0.312	15.376	185.69	1.2813	1.2896
	30 (S)		0.375	15.250	182.65	1.2708	1.2684
	40 (X)		0.500	15.000	176.72	1.2500	1.2272
	60		0.656	14.688	169.44	1.2240	1.1767
	80		0.844	14.312	160.88	1.1927	1.1172
	100		1.031	13.938	152.58	1.1615	1.0596
	120		1.219	13.562	144.46	1.1302	1.0032
	140		1.438	13.124	135.28	1.0937	0.9394
	160		1.594	12.812	128.92	1.0677	0.8953
18 OD	10	18.00	0.250	17.500	240.53	1.4583	1.6703
	20		0.312	17.376	237.13	1.4480	1.6467
	(S)		0.375	17.250	233.71	1.4375	1.6230
	30		0.438	17.124	230.30	1.4270	1.5993
	(X)		0.500	17.000	226.98	1.4167	1.5762
	40		0.562	16.876	223.68	1.4063	1.5533
	60		0.750	16.500	213.83	1.3750	1.4849
	80		0.938	16.124	204.19	1.3437	1.4180
	100		1.156	15.688	193.30	1.3073	1.3423
	120		1.375	15.250	182.66	1.2708	1.2684
	140		1.562	14.876	173.81	1.2397	1.2070
	160		1.781	14.438	163.72	1.2032	1.1370
20 OD	10	20.00	0.250	19.500	298.65	1.6250	2.0739
	20 (S)		0.375	19.250	291.04	1.6042	2.0211
	30 (X)		0.500	19.000	283.53	1.5833	1.9689
	40		0.594	18.812	277.95	1.5677	1.9302
	60		0.812	18.376	265.21	1.5313	1.8417
	80		1.031	17.938	252.72	1.4948	1.7550
	100		1.281	17.438	238.83	1.4532	1.6585
	120		1.500	17.000	226.98	1.4167	1.5762
	140		1.750	16.500	213.83	1.3750	1.4849
	160		1.969	16.062	202.62	1.3385	1.4071
24 OD	10	24.00	0.250	23.500	433.74	1.9583	3.0121
	20 (S)		0.375	23.250	424.56	1.9375	2.9483
	(X)		0.500	23.000	415.48	1.9167	2.8852
	30		0.562	22.876	411.01	1.9063	2.8542
	40		0.688	22.624	402.00	1.8853	2.7917
	60		0.969	22.062	382.28	1.8385	2.6547
	80		1.219	21.562	365.15	1.7968	2.5358
	100		1.531	20.938	344.32	1.7448	2.3911
	120		1.812	20.376	326.92	1.6980	2.2645
	140		2.062	19.876	310.28	1.6563	2.1547
	160		2.344	19.312	292.92	1.6093	2.0342
30 OD	10	30.00	0.312	29.376	677.76	2.4480	4.7067
	(S)		0.375	29.250	671.62	2.4375	4.6640
	20 (X)		0.500	29.000	660.52	2.4167	4.5869
	30		0.625	28.750	649.18	2.3958	4.5082

FIG 4-56K

Outlet Pipes and Channels

Non-pressure or gravity flow pipes and channels may be sized using Manning's formula. Various friction factors are assigned to different types of pipe or channels.

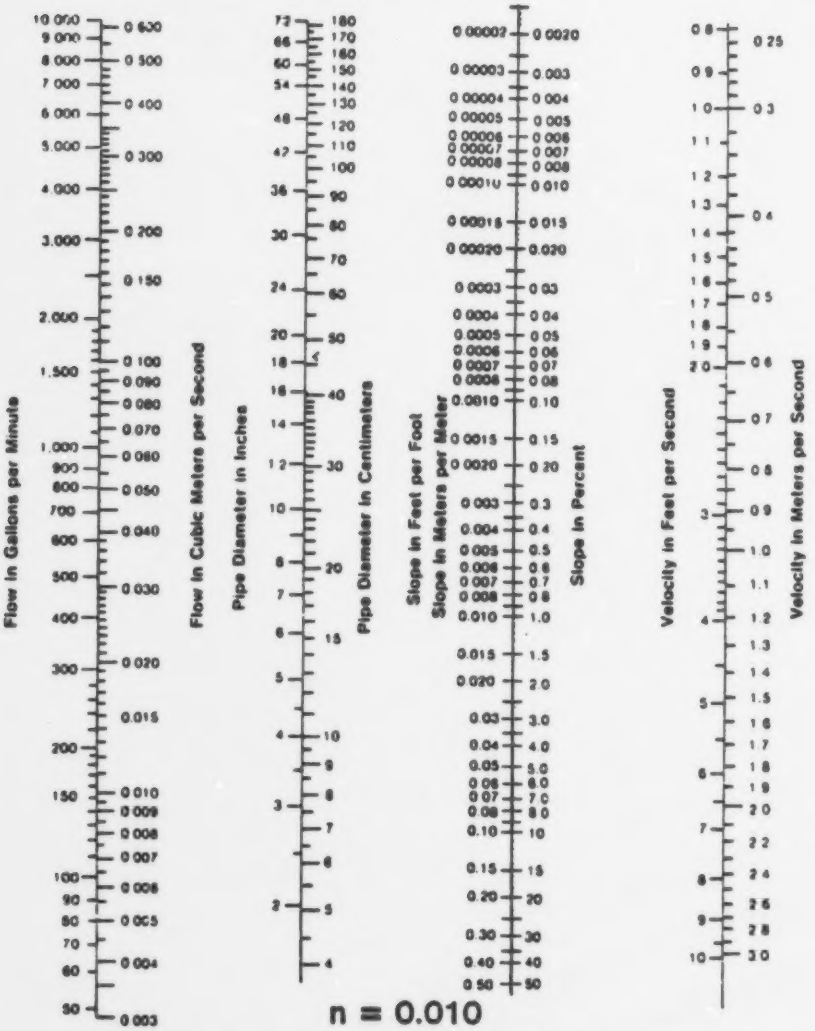
Plastic Pipe	Manning's	0.010
Steel or cast iron		0.011
Concrete, good		0.012
Concrete, poor		0.015
Corrugated pipe		0.024
Gravel channels, good		0.020
Gravel channels, poor		0.027

Work out the discharge in U.S. gpm (7.48 U.S. gallons per cubic foot) and arrive at a suitable size and slope by trial and error.

Note: Manning's numbers should be used for partly full pipes and canals. Hazen William's numbers should be used for full pipes, ie those under pressure. The nomograms can be used for canals or for pipelines where the velocity is determined by the slope and friction only.

MANNING FORMULA PIPE FLOW CHART

English/Metric Units



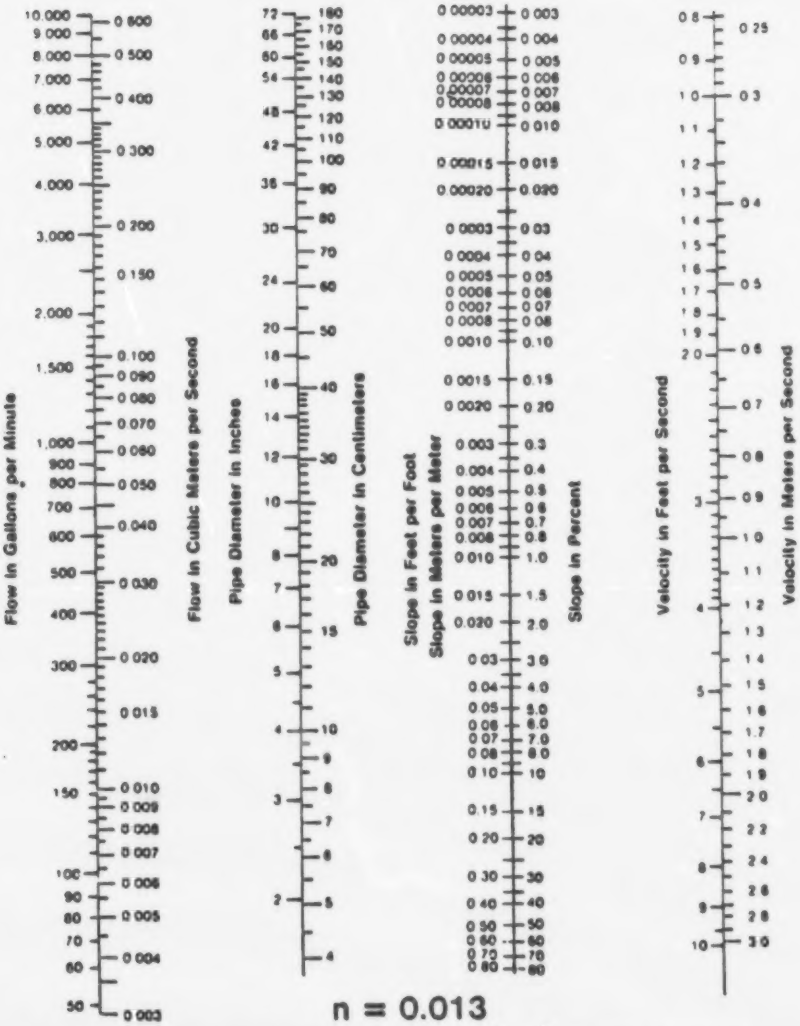
n = 0.010

Chart based on the formula $Q = \frac{1.486}{n} \times AR^{2/3} \times S^{1/2}$ for pipe flowing full.

FIG 4 - 57A

MANNING FORMULA PIPE FLOW CHART

English/Metric Units



n = 0.013

Chart based on the formula $Q = \frac{1.486}{n} \times AR^{2/3} \times S^{1/2}$ for pipe flowing full.

FIG 4-57B

MANNING FORMULA PIPE FLOW CHART

English/Metric Units

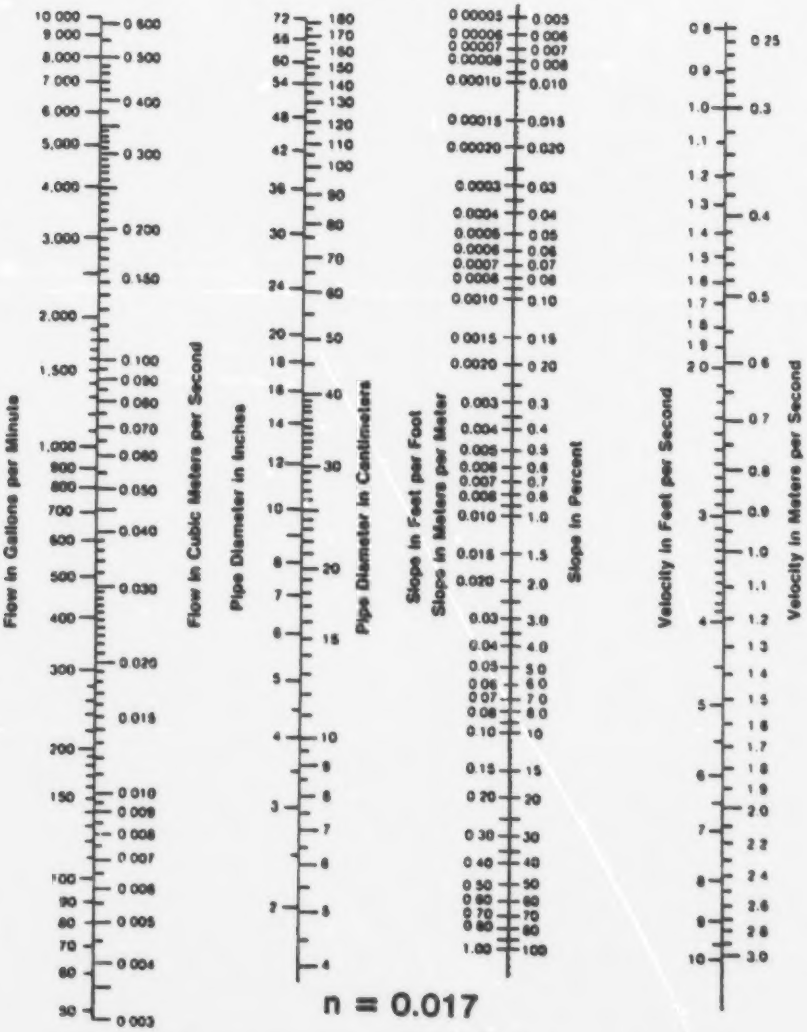


Chart based on the formula $Q=\frac{1.486}{n}\times AR^{2/3}\times S^{1/2}$ for pipe flowing full.

FIG 4-57c

Filling the Penstock

Do not attempt this until the installation is complete in every detail, and unless all concrete work is completed including thrust blocks. Leave at least 10 days to harden.

Open the bypass or drain valve, open the vacuum breaker valve (if installated) and crack the main valve at the intake to allow the penstock to flush out. Usually a certain amount of soil and mud will set in during construction. After flushing out, close the bypass valve and allow the penstock to slowly fill up (1/2 hour or so).

Testing

It is advisable to pressure test the penstock and to check for leaks, especially when using plastic pipe. Good practice calls for pressure testing as the pipe laying proceeds, usually at the half way point. The pipe is filled up with water, and is pumped up, using a hand pump and pressure gauge, to not more than the pressure class rating of the pipe. This should be done before the pipe trench is backfilled. Pressure testing is not usually done on steel penstocks unless the working pressure is high.

Testing is not always convenient when building penstocks. You should nevertheless always check for leaks when the penstock is first filled. Buried penstocks can be checked by means of a geophone, an instrument with a probe and earphones, which will sonically detect significant leaks. This should be requested after an interval of a week or two.

Suspect joints should be dug up and inspected. When significant leaks are discovered in plastic pipeline joints, it is usually necessary to cut the joint out and replace it with a repair sleeve. Minor dribbles can be ignored. One of the reasons for bedding the pipe in granular material is so that minor leakage can be harmlessly drained away.

The amount of damage a pipeline break can cause may be very serious. Good workmanship and correct methods are necessary. When working in the penstock borrow a pair of CB radios and station a man at the inlet valve so that the pipeline can be rapidly shut off in the event of trouble.

High Pressure Penstocks

The maximum available working pressure of pvc pipe is 315 psi, and for polyethylene, 250 psi. Using this as a criterion, any penstock which operates above the range of:

- PE 250 x .66 = 165 psi allowable penstock pressure, or
- PVC 315 x .66 = 208 psi allowable penstock pressure

should be considered a "high pressure penstock". You should probably change to steel pipe at about 150 psi. (346 foot head). Any penstock operating above this arbitrary limit should be designed, or at least checked by consultants or engineers. Large and/or high pressure steel penstocks may require an additional safety factor to guard against water hammer, and mechanical forces caused by settlement of the pipe supports, stress reversals during dewatering, and certain other conditions.

Low Head Penstocks

Owing to their great weight, large penstocks require very stable foundations if undue stresses in the penstock are to be avoided. Soil mechanics and foundation design are major factors, in the need for professional design.

4.10 FORCES AND THRUST BLOCKING

Two forces must be considered: static loads due to the weight of the pipe when full of water, and dynamic loads caused by the force of the flowing water. Momentum may become significant on large diameter high and low head penstocks, but is usually disregarded on small scale plants. Water flowing through pipe bends causes forces which tend to straighten the pipe. This force can be quite high, and may pull the pipe joints apart if they are not properly restrained by means of thrust blocks.

For example, consider a six-inch pipe operating on a 200 foot head. A 90-degree bend in this pipe will cause a force of 3500 pounds at the bend. Plastic and steel pipe must be very carefully thrust whenever the deviation exceeds seven degrees.

Pipeline Thrust

The following formula for pipeline thrust will give good approximations when used for small hydro applications:

$$\text{Thrust} = 1.57 \times S \times D^2 \times \text{Sin } a$$

where Thrust is in lbs,
S = static pressure in lbs/sq. inch
D^2 = outside diameter of pipe, squared, (in inches squared)
a = angle of change

Sin = sine of the angle of change. (sin 20 = 0.34; sin 30 = 0.5; sin 45 = 0.7; sin 60 = 0.86) Prorate for other values, or see trigonometric tables.

Psi = change head to Psi by multiplying head in feet by 0.433, the pressure of one foot of water.

Fig. 4-58 provides a range of standard thrust block designs.

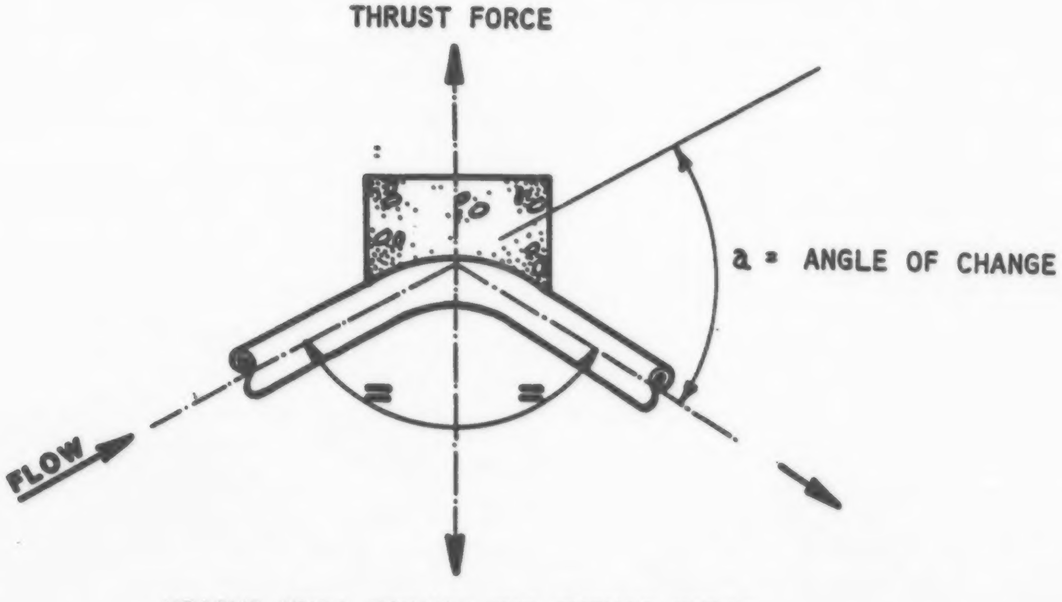
Example: Thrust on Pipe Bend

Eight inch penstock operating at 190 ft head with a 30° horizontal bend. Final force in the bend:

Psi = 190 x 0.433 = 82.27 Psi
Sine 30° = 0.5

$T = 1.57 \times 82.27 \times 8^2 \times 0.5 = \underline{4133.2}$ Lbs, over two tons!

The angle at which this force acts is at the mid point between the two centre lines of the pipes.



WEIGHT MUST RESIST THE THRUST FORCE

FIG.4-58 PIPE THRUST AT BENDS

Thrust Block at Vertical Bend

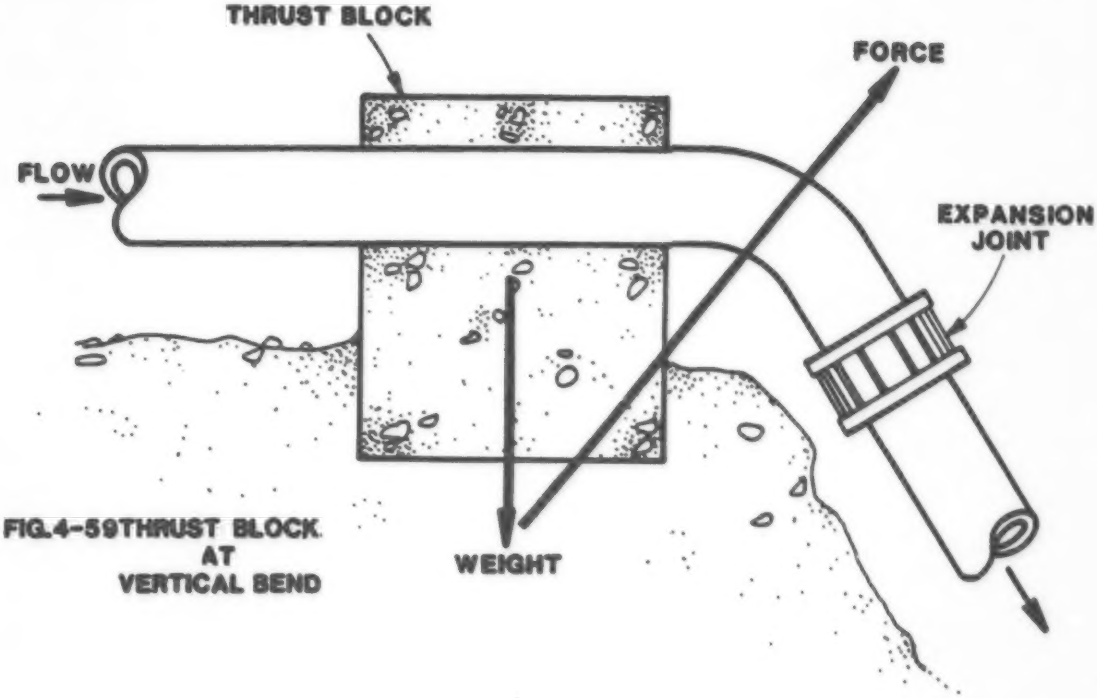

THRUST BLOCK
FORCE
FLOW
EXPANSION JOINT
WEIGHT

FIG.4-59THRUST BLOCK AT VERTICAL BEND

For vertical drops, the thrust block must be heavier than the thrust force by at least 50 percent. Work out a more or less cubic shape, assuming a concrete weight of 3500 lbs/cu.yd.

Thrust Pad on Vertical Bend

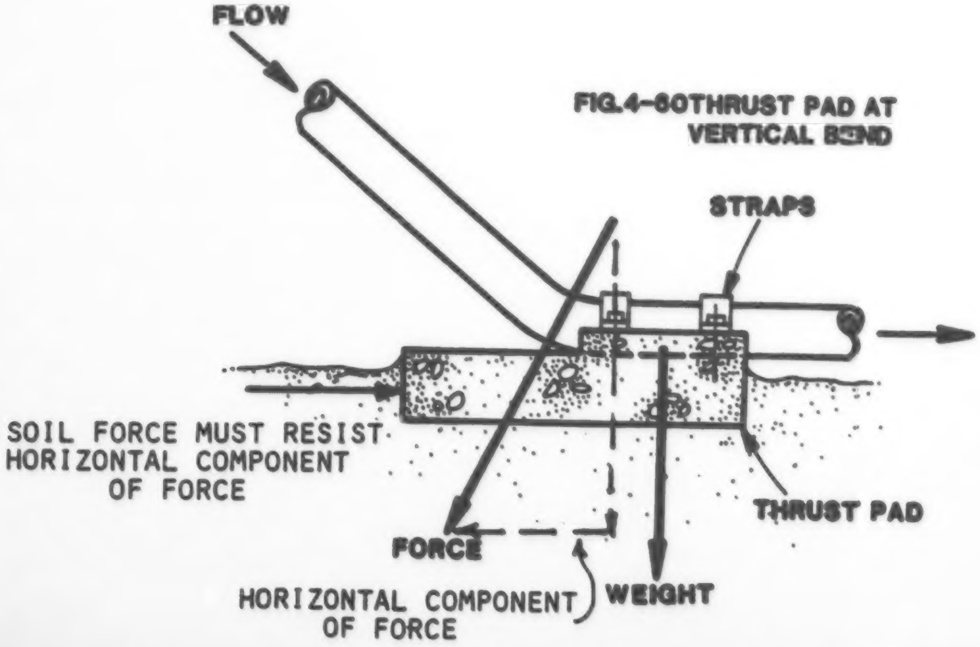

FLOW
STRAPS
SOIL FORCE MUST RESIST HORIZONTAL COMPONENT OF FORCE
THRUST PAD
FORCE
HORIZONTAL COMPONENT OF FORCE
WEIGHT

FIG.4-60THRUST PAD AT VERTICAL BEND

Area of base must be such that the bearing pressure against the subsoil is acceptable.

Table of Soil Bearing Capabilities,
Vertical Loads

	Tons per square foot		
Rock	- 60-100	Clay	- 1-4
Shale	- 10	Peat	- 0
Sand	- 1-2	Hardpan	- 10
Gravel	- 4-5		

Considering the bearing strength of average soils subjected to vertical loads, a pad three pipe diameters each way and about one pipe diameter thick is generally sufficient. The pad should have a groove or strap on the top to hold the pipe in position, or the pad can be cast around the pipe. See Figure 4-59 through 4-61.

Note: the allowable bearing pressure on soils subject to horizontal loads is much less than for vertical loads. Do not use soil bearing pressure tables directly for horizontal loads. A safe value, assuming undisturbed earth, would be 50% of vertical loading.

Thrust blocking in plastic pipe may have bearing area requirements between the pipe and the thrust block. See manufacturers recommendations. Every effort should be made to avoid pipe bends over 30°, because much more concrete is necessary to adequately restrain them.

Concrete Pilaster at Pipe Ends

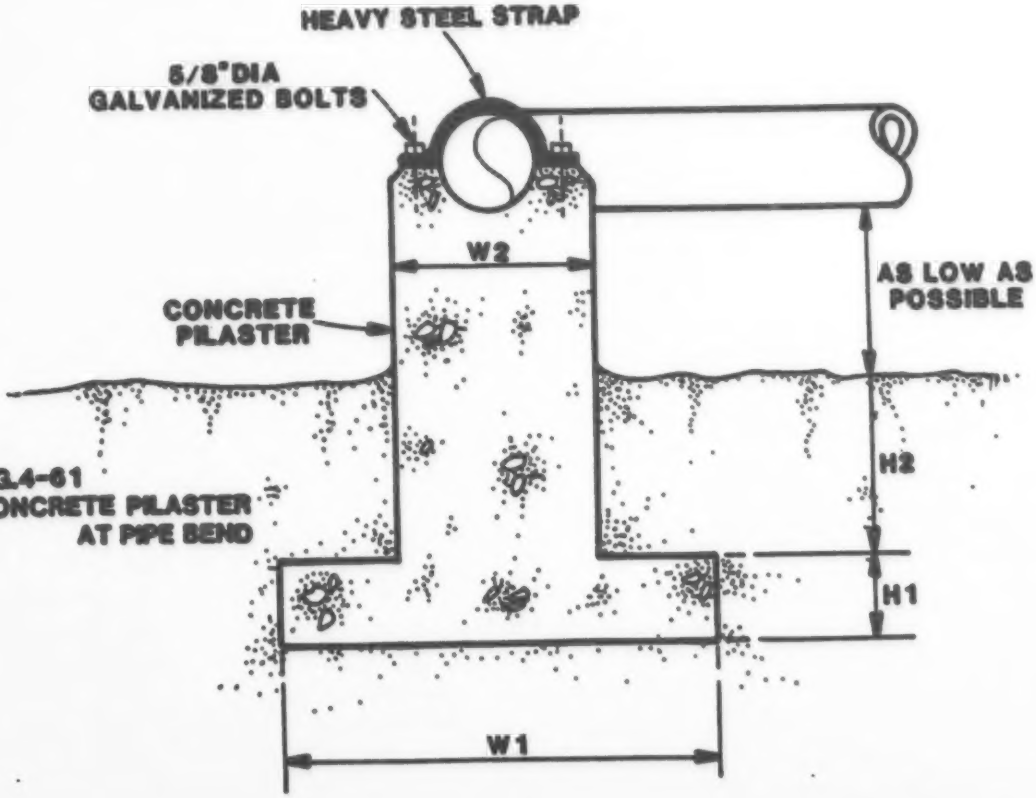


FIG.4-61
CONCRETE PILASTER
AT PIPE BEND

Concrete pilasters are suitable for pipe not exceeding 12" diameter. Pilasters for pipes exceeding 12" diameter and higher than 18" above the ground surface must be custom designed.

General Rule

H1 should be 1 1/2 pipe diameters, and H2 should be four pipe diameters, W1 should be five pipe diameters each way, and one pipe diameter thick, W2 should be 1 1/2 pipe diameters square.

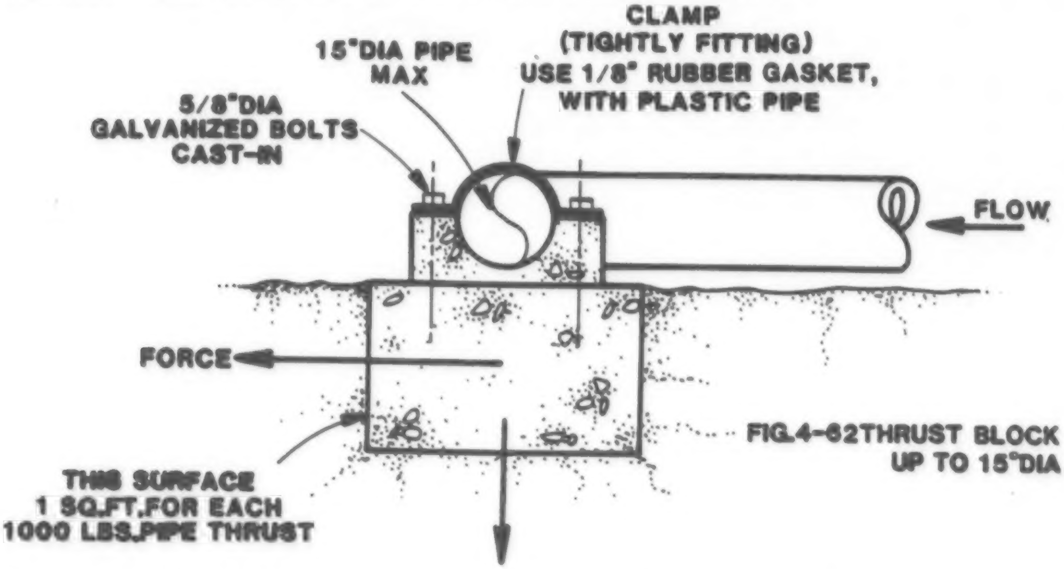

CLAMP
(TIGHTLY FITTING)
USE 1/8" RUBBER GASKET,
WITH PLASTIC PIPE
15"DIA PIPE
MAX
5/8"DIA
GALVANIZED BOLTS
CAST-IN
FLOW
FORCE
THIS SURFACE
1 SQ.FT.FOR EACH
1000 LBS.PIPE THRUST

FIG.4-62THRUST BLOCK
UP TO 15"DIA

Thrust Blocking for Penstock Descending Steeply Pitched Hillside

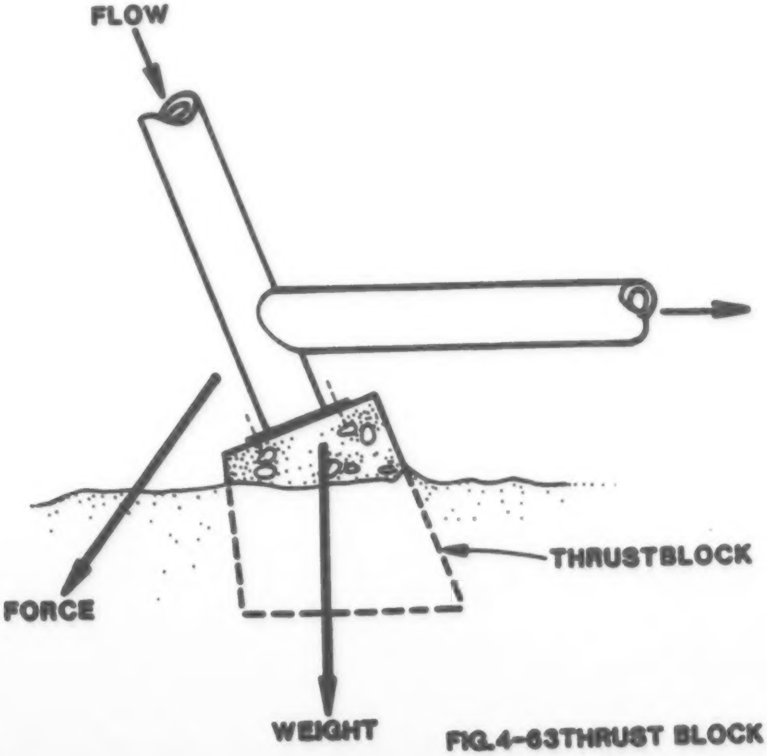

FLOW
THRUSTBLOCK
FORCE
WEIGHT

FIG.4-63THRUST BLOCK

Thrust Blocks at the Power House

Two conditions must be met:

1. The thrust block prevents the penstock from sliding downhill;
2. The powerhouse thrust block restricts thermal expansion and contraction of the penstock to the section uphill from the thrust block. An expansion coupling is used in the power plant to provide for minor changes between the thrust block and turbine and to provide a slight flexibility at this point.

If thrust blocks are placed at 200 foot intervals, the section of penstock able to slide downhill is 200 foot long. Because of friction against the penstock cradles, the actual force to be resisted is quite laborious to determine accurately and must be calculated for each case.

Thrust blocking of steel pipe should not be more than 200 feet apart.

Expansion Joint at Each Thrust Block

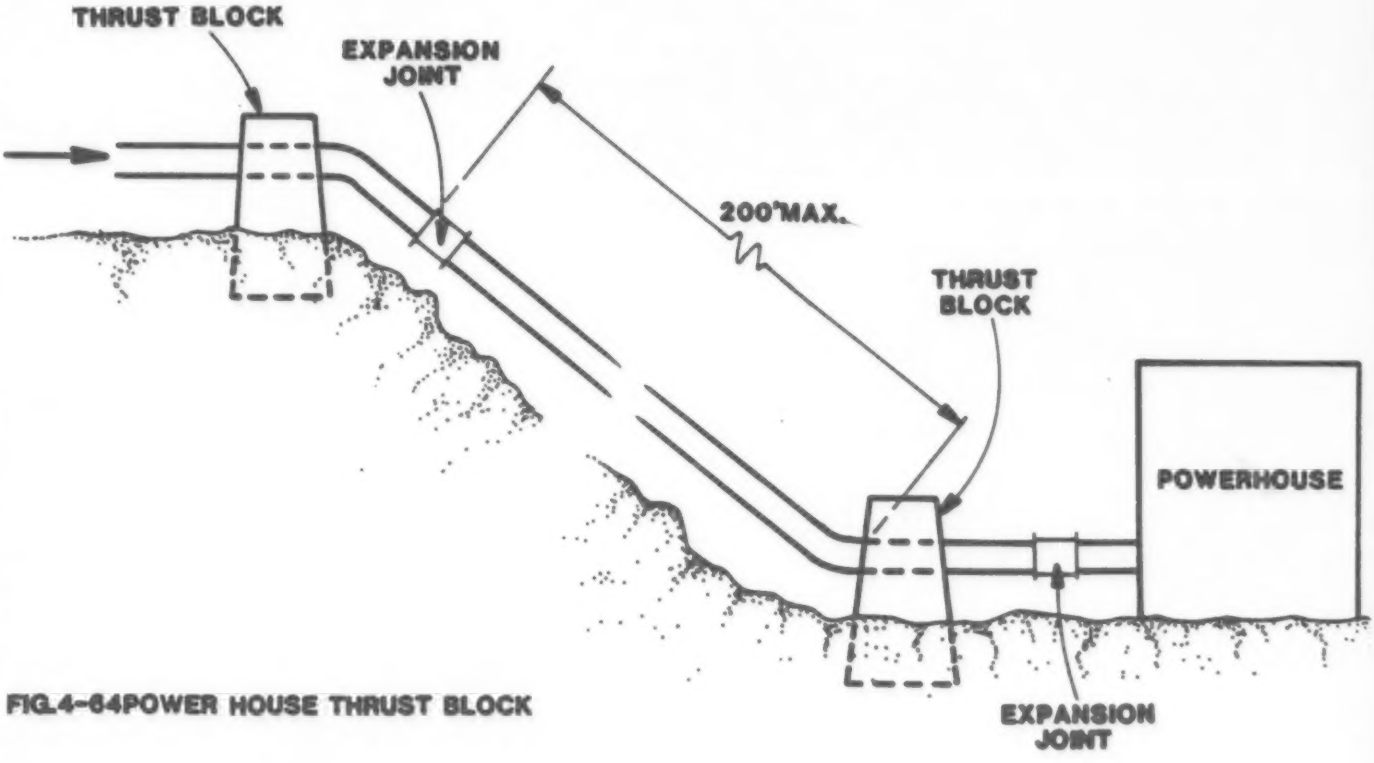


FIG.4-64 POWER HOUSE THRUST BLOCK

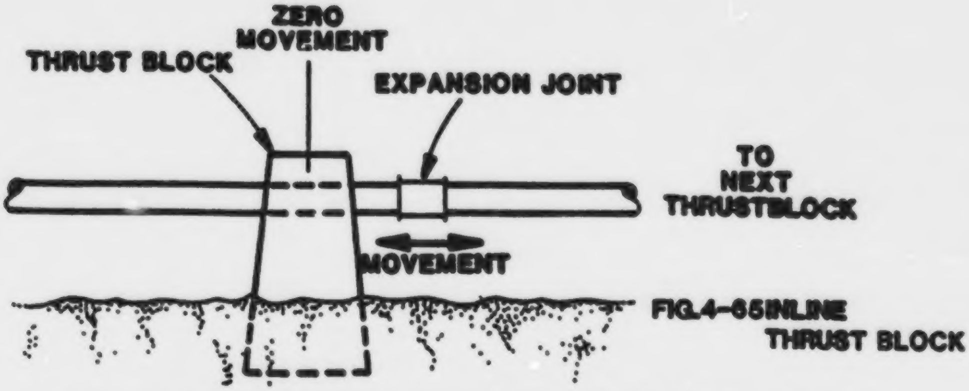

ZERO
MOVEMENT
THRUST BLOCK
EXPANSION JOINT
TO
NEXT
THRUSTBLOCK
MOVEMENT

FIG.4-65 INLINE THRUST BLOCK

Penstock Thrust Block at Powerplant for Small Plastic Pipe (6" to 14")

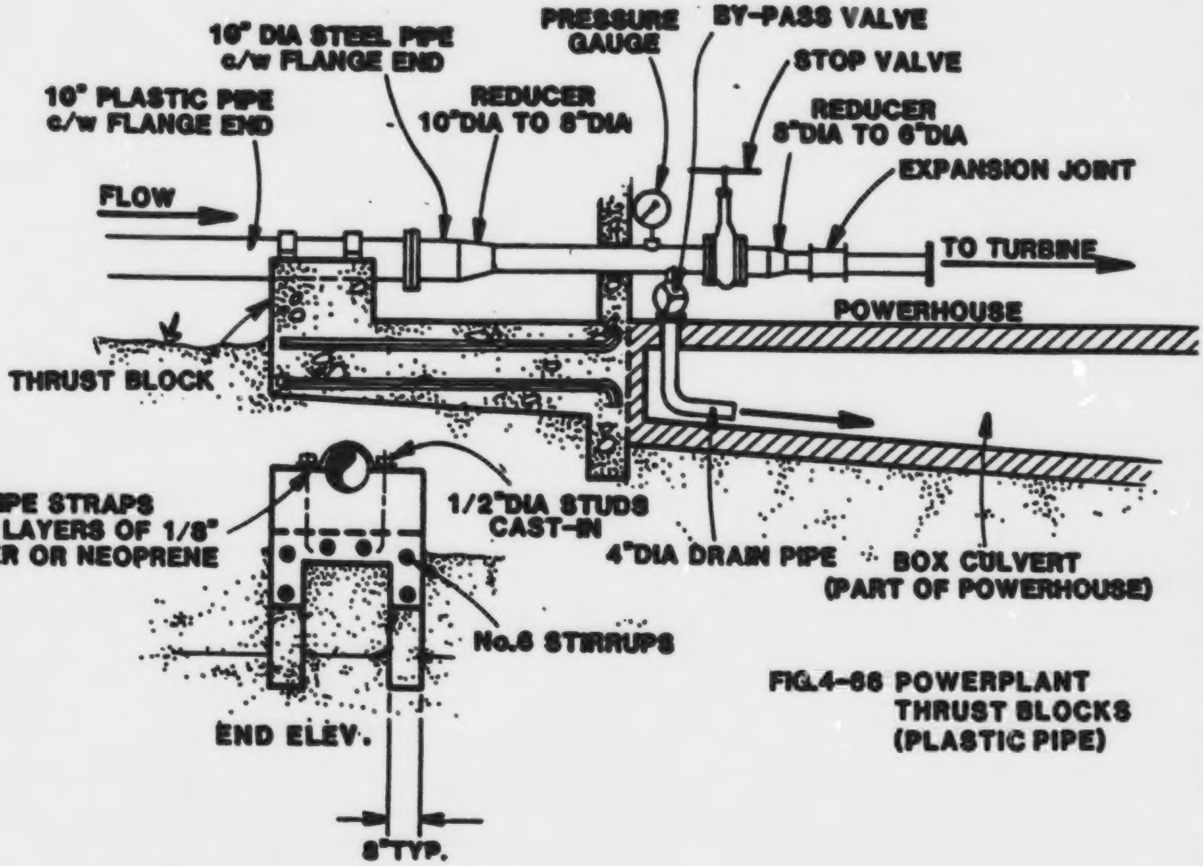

10" DIA STEEL PIPE
c/w FLANGE END
PRESSURE
GAUGE
BY-PASS VALVE
STOP VALVE
10" PLASTIC PIPE
c/w FLANGE END
REDUCER
10"DIA TO 8"DIA
REDUCER
8"DIA TO 6"DIA
EXPANSION JOINT
FLOW
TO TURBINE
POWERHOUSE
THRUST BLOCK
PIPE STRAPS
c/w 2 LAYERS OF 1/8"
RUBBER OR NEOPRENE
1/2"DIA STUDS
CAST-IN
4"DIA DRAIN PIPE
BOX CULVERT
(PART OF POWERHOUSE)
No.6 STIRRUPS
END ELEV.
8"TYP.

FIG.4-66 POWERPLANT THRUST BLOCKS (PLASTIC PIPE)

Powerhouse Thrust Block, Steel Pipe

See Figure 4-67.

The base must carry the weight of pipe and water to the next upstream thrust block. Where possible, the thrust block should be tied into a rock foundation. Otherwise, resistance to sliding must be adequate under local soil strength.

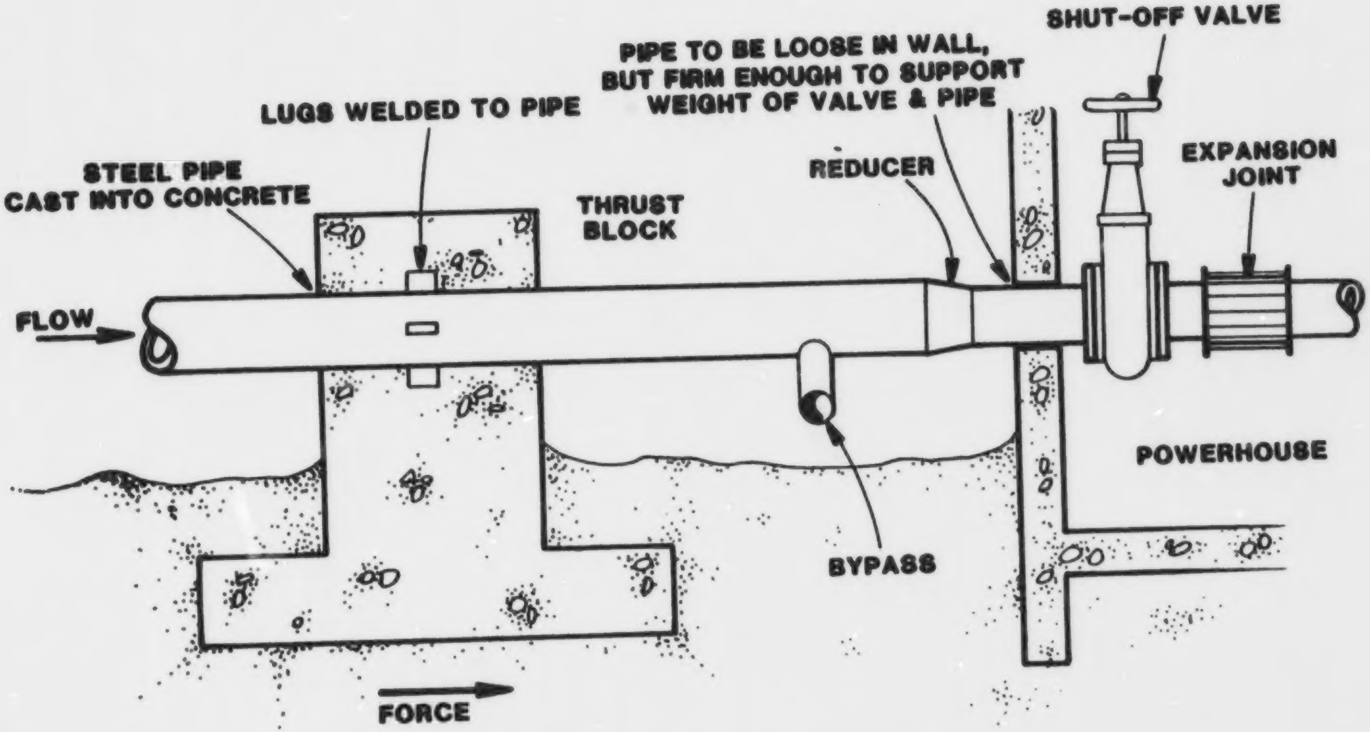

SHUT-OFF VALVE
PIPE TO BE LOOSE IN WALL, BUT FIRM ENOUGH TO SUPPORT WEIGHT OF VALVE & PIPE
LUGS WELDED TO PIPE
EXPANSION JOINT
STEEL PIPE CAST INTO CONCRETE
REDUCER
THRUST BLOCK
FLOW
POWERHOUSE
BYPASS
FORCE

FIG.4-67POWERHOUSE THRUST BLOCK (STEEL PIPE)

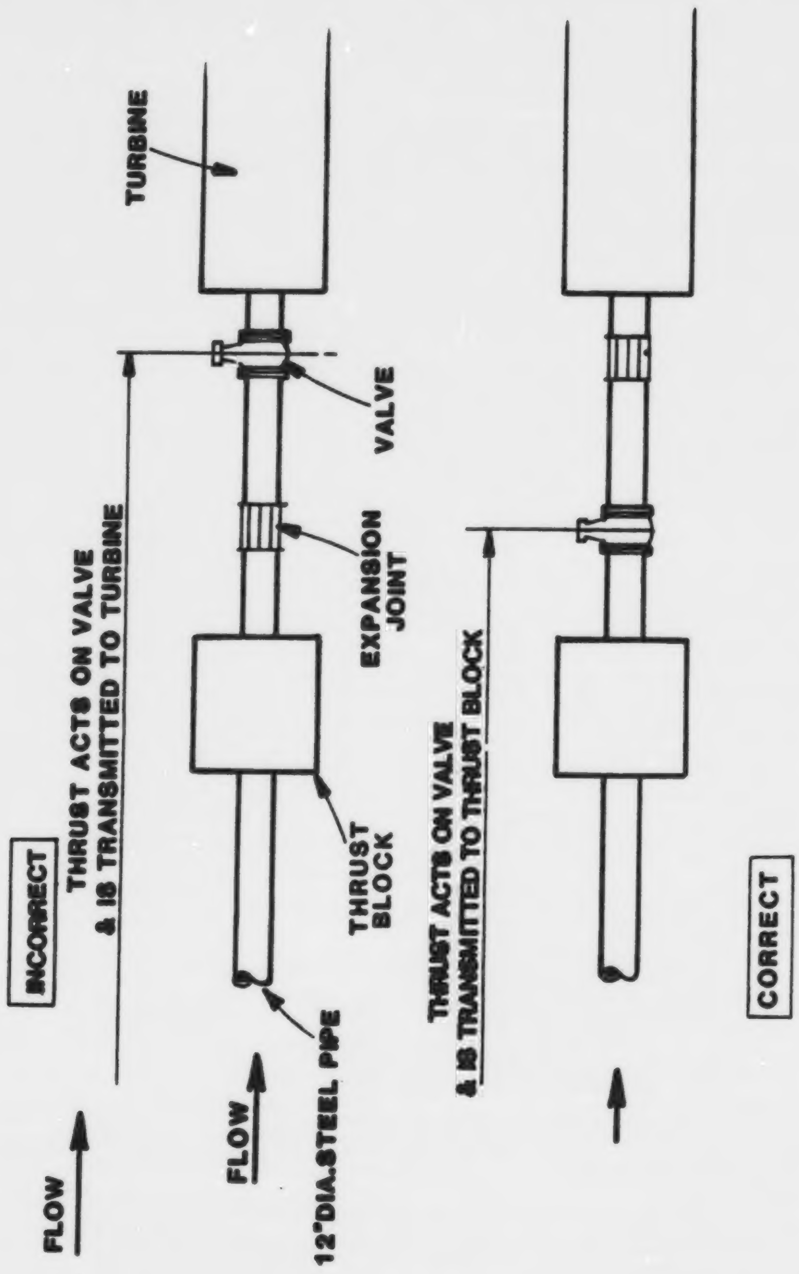

FLOW
FLOW
12"DIA.STEEL PIPE
INCORRECT
THRUST ACTS ON VALVE
& IS TRANSMITTED TO TURBINE
TURBINE
VALVE
EXPANSION
JOINT
THRUST
BLOCK
THRUST ACTS ON VALVE
& IS TRANSMITTED TO THRUST BLOCK
CORRECT

FIG.4-68 THRUST & EXPANSION JOINT POSITIONING

Powerhouse thrust blocks should be professionally designed for pipes greater than eight inch diameter or for pressures above 90 psi.

4.11 INSTALLATION OF PENSTOCKS

Penstock Routing

The ideal penstock would be short, direct, and steep. This is virtually impossible to achieve, but every effort should be made to locate a route which is as close as possible to the ideal.

Buried Penstocks

Above ground penstock installation is preferrable where freezing is not a problem because far more latitude is available for route selection. Try to ensure that the pipeline route is accessible to vehicles, preferably throughout; but otherwise in locations reasonably close together. Hauling steel pipe into position using a 4-wheel vehicle drive winch is sometimes possible. Select a route which is on a consistent downhill gradient. Reduce horizontal bends and deviations to a minimum. When changes in direction are necessary, try to make gradual changes consisting of a series of 15° or 30° bends. Consider the location of thrust blocks to minimize the necessity for their use. The volume of concrete which has to be carried into the bush can be reduced by careful planning.

In severe frost areas, penstocks should always be buried below the frost line. Parts of the pipeline which rise above the frost line must be insulated. See Chapter 9.

The route must be accessible to a backhoe. Material along the route must be excavatable with little or no blasting. (See Balancing of Losses). Routing a buried pipe alongside the stream may involve dealing with large, awkward boulders. Pipelines are vulnerable to washouts if placed anywhere near the stream. As soon as hydraulic gradient permits, leave the stream bed by angling the pipe along the stream bank. The going is usually better away from the water course. Try to ensure that the pipe wanders a little in the trench to allow for temperature changes.

Typical Trench Profile

When using plastic pipe check with manufacturers for maximum buried depth. You may have to increase wall thickness for deep pipes.

See Figure 4-69.

The trench width should be two pipe diameters, more if access to the pipe is required to join or connect it. If a trench more than four feet deep is required, shoring or sloping of the sides is required by Workers Compensation safety code.

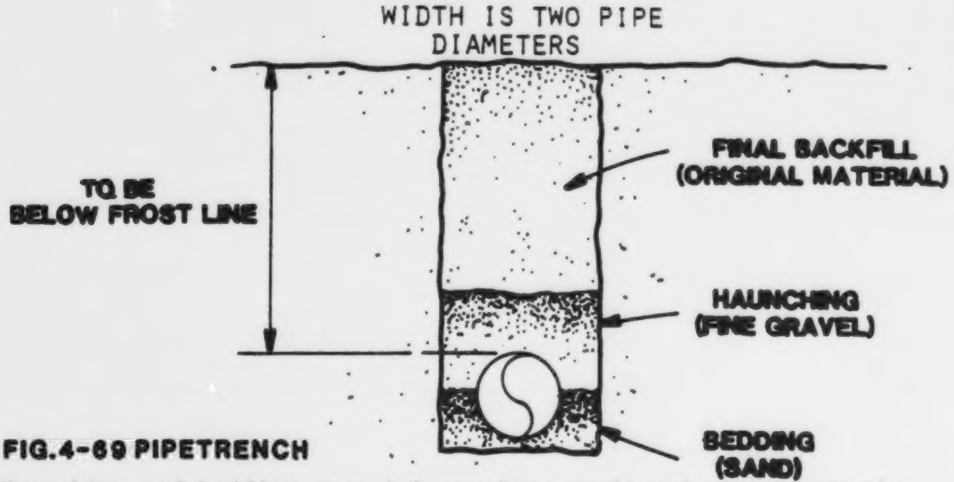

WIDTH IS TWO PIPE
DIAMETERS
TO BE
BELOW FROST LINE
FINAL BACKFILL
(ORIGINAL MATERIAL)
HAUNCHING
(FINE GRAVEL)
BEDDING
(SAND)

FIG.4-69 PIPETRENCH

Haunching and bedding material are fine sands and clayey gravel, granular and non-cohesive. Maximum size of stones is 1 1/2 inches. These layers must be firmly but not excessively tamped. Initial backfill uses the same material compacted in six-inch layers. Final backfill uses excavated trench materials with all rocks larger than six inches removed.

Above Ground Penstocks

Plastic pipe is usually laid directly on the ground, and kept aligned by packing earth around it every few feet.

Plastic Pipe Laid on Ground

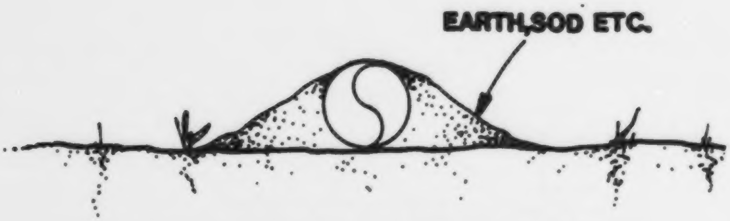

EARTH,SOD ETC.

FIG.4-70PLASTIC PIPE LAYED ON GROUND

All bends over seven degrees must be thrust blocked. Cradles should be used to support the pipe on steep downhill sections, rock faces, side hills, etc. A variety of cradles and supports are illustrated, Fig 4-81 to Fig. 4-92. Polyethylene pipe should be fully supported on the ground, and where cradles are necessary they must be close together: not over eight to ten feet apart for sizes larger than twelve inches, and six to eight feet apart for six to ten inches.

PVC and steel can be supported at less frequent intervals. Fig 4-77 shows cradle spacing. Steel pipe should be supported clear of the ground on damsack timber, concrete blocks, or saddles, as this helps to limit corrosion. Timber saddles should be preservative treated.

Rising Pipeline

Polyethylene pipe can be pulled into long curves. Minimum radius of bend is diameter in inches x 50. For example, 8" x 50 = 400" (33 ft). For PVC pipe, minimum radius is diameter of pipe x 300. Attempting to use smaller radius bends for either type of pipe will overstress the material and cause cracking or flattening.

Sweep Bends in Plastic Pipe

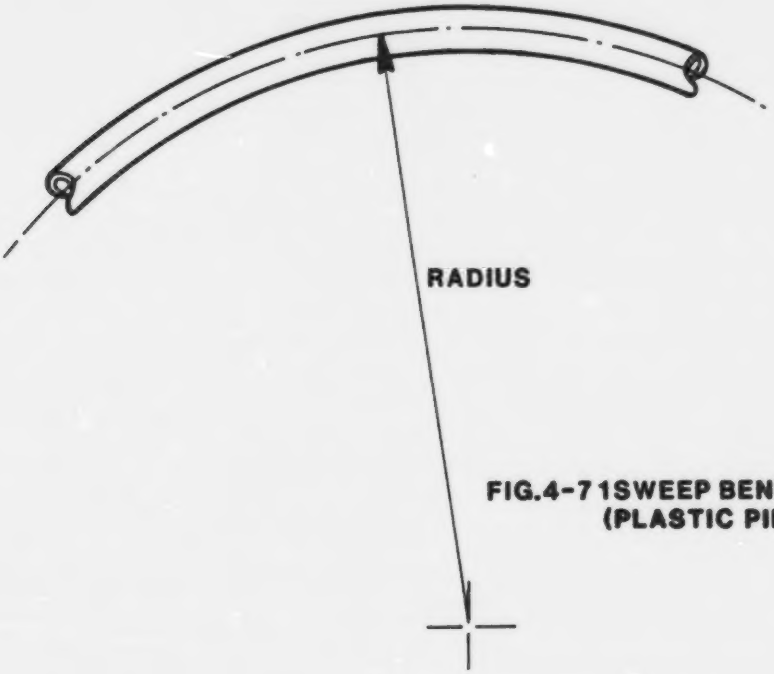


FIG.4-71SWEEP BENDS (PLASTIC PIPE)

To thrust block a sweep bend in plastic pipe, calculate the force on the bend (Section 4-8) and distribute it over two to three evenly spaced thrust blocks along the bend.

Continuously welded steel pipelines can be gradually snaked. Full bends usually use formed bends or mitre joints. Dresser type couplings will accept up to five degree deviation, and can be used to make long radius bends.

Plastic and steel pipes installed above ground should never be restrained except at thrust blocks. Pipes need to be free to move with temperature changes. Expansion joints must be used at rigid thrust blocks when using steel pipe, and these should be no further apart than 200 ft. Cable restraints can be used on steep slopes.

Expansion Joints

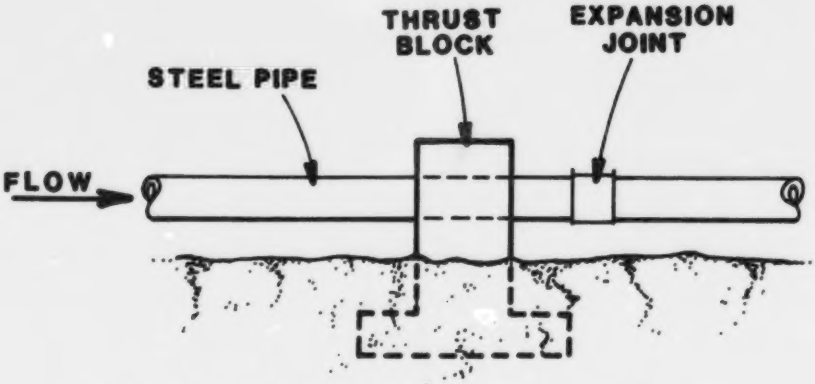


FIG.4-72EXPANSION JOINT AT THRUST BLOCK

Plastic pipe installed above ground will not require expansion joints, provided the pipe is not restrained in any way except on steep slopes. Expansion is taken up by squirming and by actual compression of the pipe material. Steel pipes tend to be more of a problem.

Theoretically, a dry pipe will heat to a temperature above the ambient temperature in sunny weather, and can easily heat to temperatures up to 120°F.

Example:

1153 ft of steel pipe

Temperature range, say 40°F to 150°F = 80°F

Coefficient of expansion for steel = 0.000076 inches per foot per 1°F.

Therefore expansion = 1153 x 0.000076 x 80 = 7.01 inches

Allowing 3/8" per expansion joint, theoretically about 18 expansion joints would be necessary. Actually fewer would suffice, since much of the expansion is taken up by axial squirming along loosely restrained pipe. One manufacturer recommends expansion joints at 200 foot intervals on small unrestrained penstocks. In our example this would mean six expansion joints along the route, plus one at the power house.

Professional Advice

Pipe manufacturers are usually willing to supply brochures, pipe standards, and installation details. Installation involving pipe larger than twelve inches, or pressures above 150 psi (the limit for plastic penstocks) should receive professional attention. Certain aspects of pipe installation, such as minimum wall thickness for buried pipe, are complex problems too lengthy to discuss here. Consult the pipe supplier before committing yourself to purchase.

Vacuum

The effect of an internal vacuum is the application of the ambient barometric pressure to the outside of the pipe. This pressure amounts to 14.7 psi at sea level for a perfect internal vacuum. Since this is not possible, a maximum vacuum of 0.6 x 14.7 psi (8.82 psi) is usually assumed. This pressure is sufficient to collapse large diameter penstocks whether they are steel or any other material. Plastic pipe of any size is particularly vulnerable to vacuum collapse.

Vacuum would be caused by shutting off the penstock at the intake whilst permitting water to run out the lower end. This condition is prevented by means of a vacuum breaker pipe installed at the downstream end of the intake valve. This pipe, which should be about 25 percent of the penstock diameter, allows air to replace the water as it recedes, and opens the pipe to barometric pressure.

Vacuum effects may have to be considered in buried pipes, where the soil pressure would add to the vacuum loads.

Pipes in Heavily Wooded Areas

Small pipes laid on the forest floor gradually disappear under leaf mold and vegetation. This adds useful thermal insulation. Small pipes (up to eight-inch plastic, twelve-inch steel) will be fairly safe against falling trees if dead falls and danger trees are cut and laid along the pipe. Extensive clearing and falling can be avoided for small pipelines if lengths up to one hundred feet or so are welded together at some accessible place, then hauled into position. The lengths can be coupled together with expansion joints.

For larger pipes, say eight inches and over, a trail is necessary because either a welding generator or a plastic welding jig must be used.

In some instances, the penstock can follow the intake access road. When installing penstocks, cutting wide swaths through the forest is not always aesthetically reasonable or justifiable. Trees are often cut back to outside the falling reach of the penstock. However, when this cannot be done, dangerous trees should be cut regularly and placed alongside the penstock.

High pressure, above ground penstocks are liable to rupture or severe damage, and therefore trees within falling distance should be cut back, particularly on the lower reaches. Most types of plastic pipe will regain their original shape when squashed by falling trees, however sometimes the pipe must be cut and fitted with a flanged section. Repair sleeves are available for most pipes.

Figure 4-73 to Figure 4-75 illustrates a variety of pipe installation details.

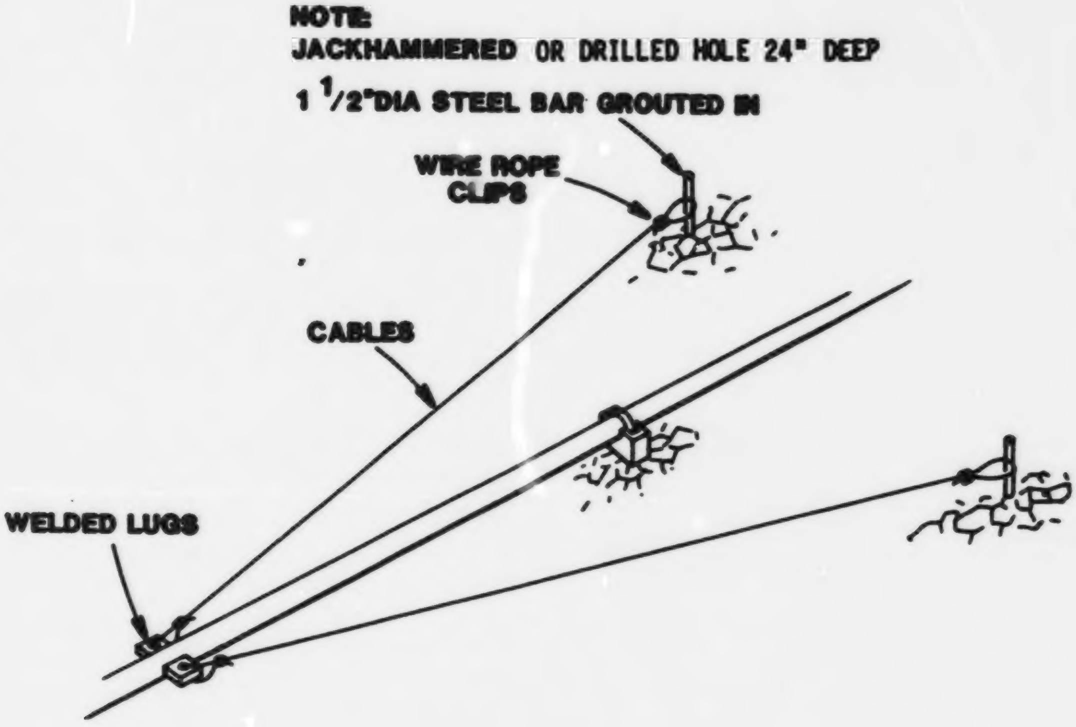

NOTE:
JACKHAMMERED OR DRILLED HOLE 24" DEEP
1 1/2"DIA STEEL BAR GROUTED IN
WIRE ROPE CLIPS
CABLES
WELDED LUGS

FIG.4-73CABLE STAYS

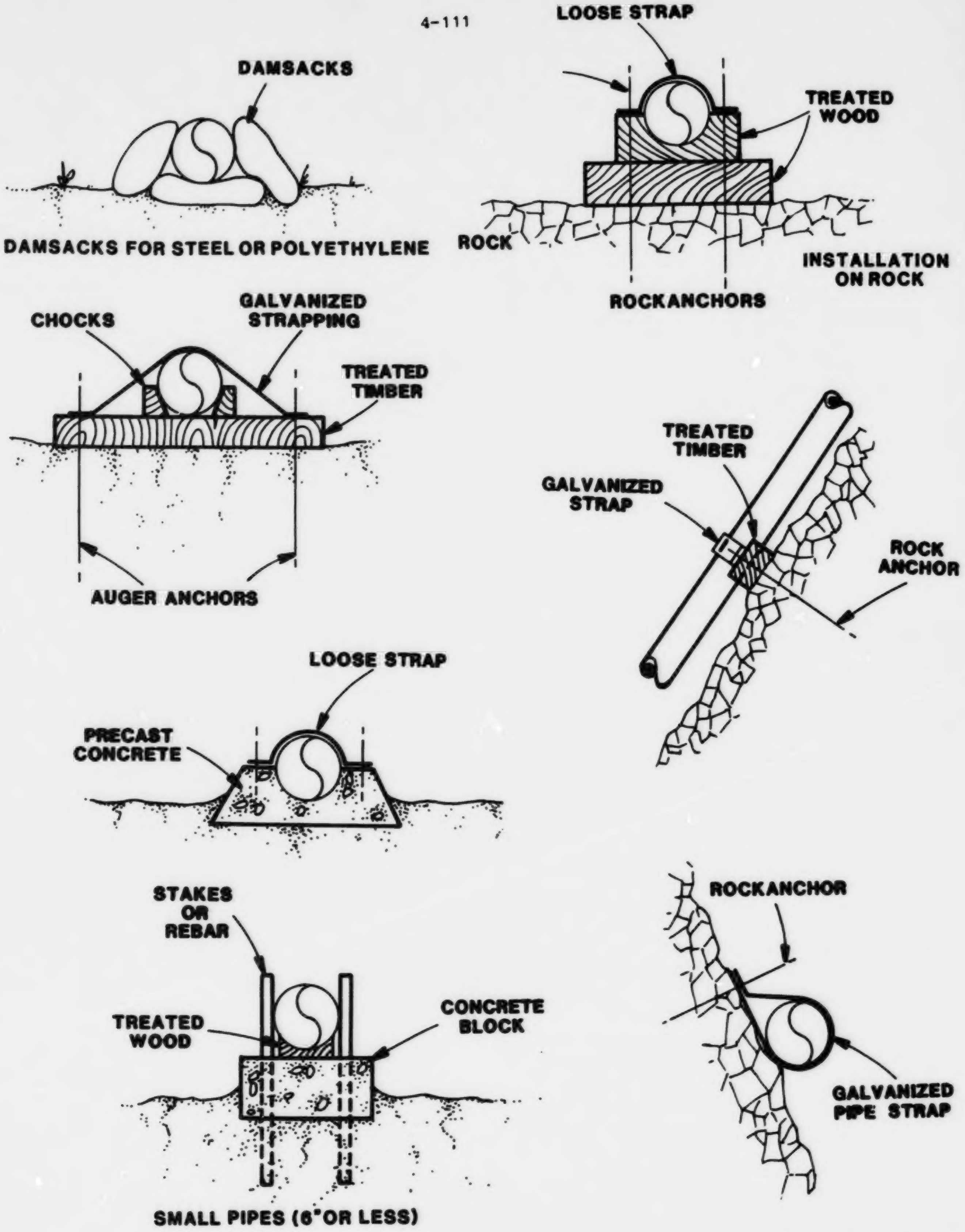
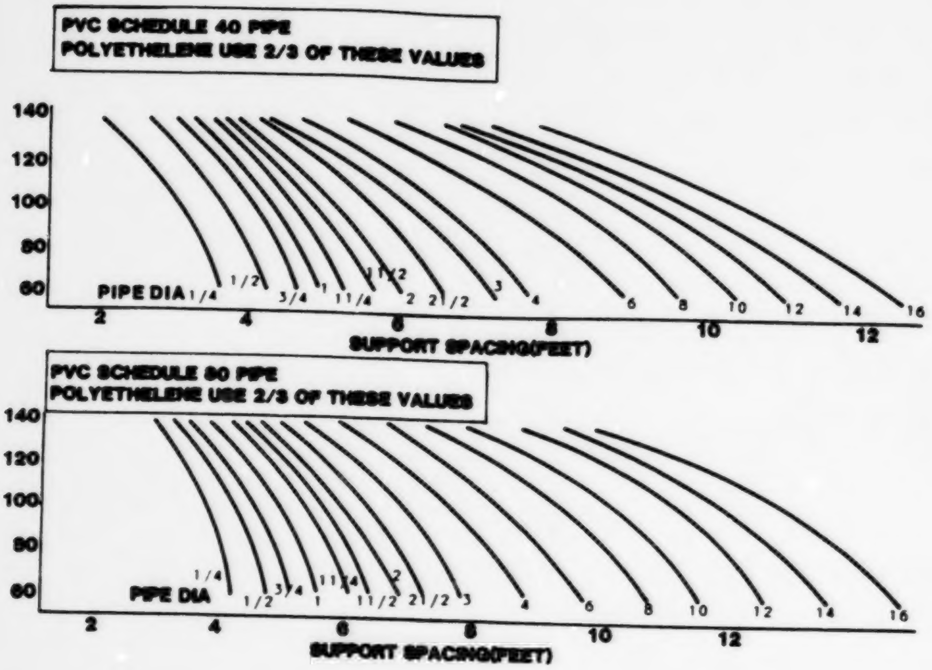
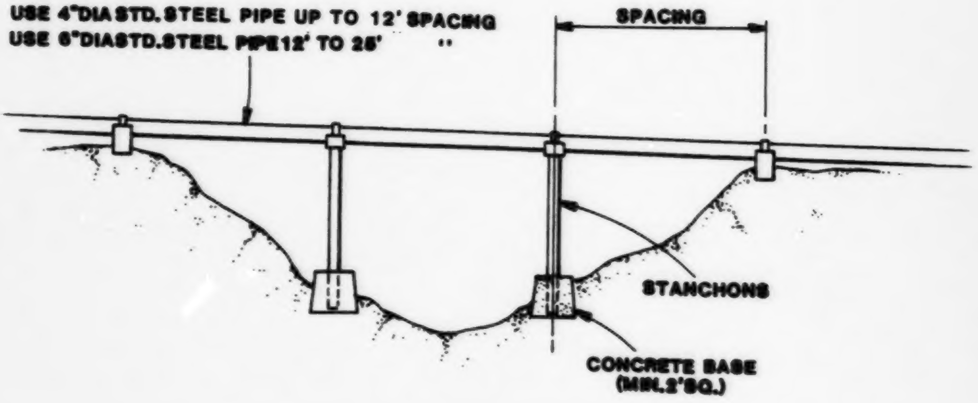

DAMSACKS
DAMSACKS FOR STEEL OR POLYETHYLENE
LOOSE STRAP
TREATED WOOD
ROCK
ROCKANCHORS
INSTALLATION ON ROCK
CHOCKS
GALVANIZED STRAPPING
TREATED TIMBER
AUGER ANCHORS
TREATED TIMBER
GALVANIZED STRAP
ROCK ANCHOR
LOOSE STRAP
PRECAST CONCRETE
STAKES OR REBAR
TREATED WOOD
CONCRETE BLOCK
SMALL PIPES (6"OR LESS)
ROCKANCHOR
GALVANIZED PIPE STRAP

FIG.4-74 PIPE INSTALLATION DETAILS



STEEL & PLASTIC PIPE		
PIPE DIA. (INCHES)	SUPPORT SPACING (FEET)	METRES
4	14	4.3
6	17	5.2
8	19	5.8
10	20	6.1
12	23	7.0
14	25	7.6
16	27	8.2
18	28	8.5
20	30	9.1
24		9.6
30	33	10.1

FIG.4-75PIPE SUPPORT SPACING


USE 4"DIA STD.STEEL PIPE UP TO 12' SPACING
USE 6"DIA STD.STEEL PIPE 12' TO 25' "

SPACING
STANCHONS
CONCRETE BASE
(MIN.2'SQ.)

FIG.4-75 A SUPPORT SPACING

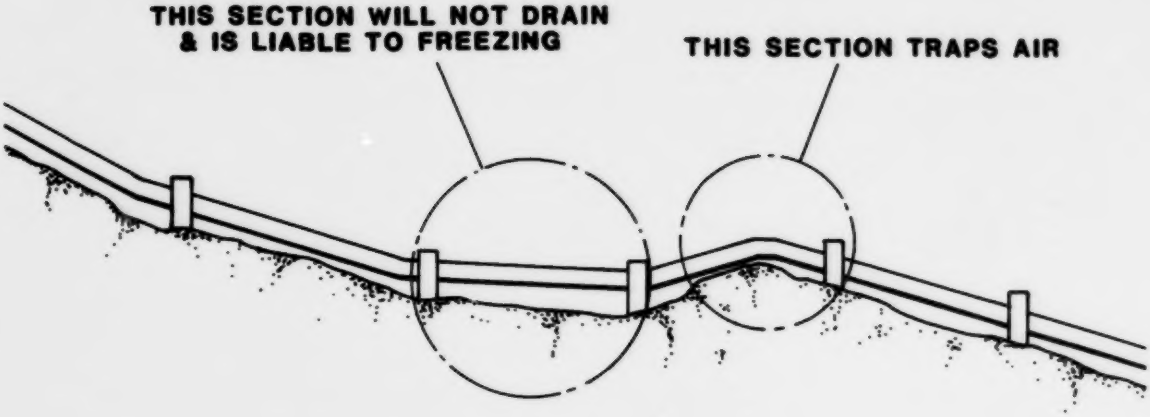


FIG.4-76RISING PENSTOCKS

4.12 WATER HAMMER

Cause, Effects, and Prevention

Water hammer is a change of pressure, either above or below the normal pressure, and is caused by a rapid change in the rate of flow in the pipe. The result is a sudden mechanical shock which can cause damage to the pipe and fittings.

The water in the penstock has momentum equal to the mass of the water multiplied by its velocity. When a valve is closed, the momentum falls to zero. This change causes a pressure rise which starts at the valve and travels up the pipe. The kinetic energy in the water must be converted to pressure, and the pressure rise will continue until it is high enough to overcome the momentum and stop the water flow. The pressure wave travels up the reservoir where the higher pipe pressure causes water to rush back into the reservoir. As the water flows back into the reservoir, the pipe pressure drops causing a negative pressure wave to travel down the penstock to the valve. At this point, the water has considerable momentum up the pipe so that a low pressure is caused at the valve. Differential pressure again causes the water to stop, and water now rushes back into the pipe. This cycle of events continues until friction damping eventually returns the system to normal.

Sudden changes in water velocity can occur in two ways: either by the sudden closure of a valve, or by a rapid governor operation which suddenly changes the flow rate. Governor speed is closely related to water hammer. Rapid governor operation is desirable to minimize speed changes or load fluctuations, and yet should this be too fast for the penstock, water hammer will occur. On the other hand, slow governor action may allow excessive speed rise or load rejection. This is a complex design problem for small hydro turbine systems and explains the use of flywheels to limit the rate of speed change.

Water hammer can be quite severe in steel pipes when the water velocity is high, but its strength gives steel the ability to resist water hammer. The water hammer effect in pvc and polyethylene is much less, about one/fifth that for steel. Water hammer stresses are usually not severe in small pipes with low to moderate flow velocity of four to five feet per second.

Slow closing valves, such as gate valves, should be used on penstocks, because fast acting valves, such as butterfly or spherical valves, can cause severe water hammer.

Water hammer can be prevented from reaching dangerous valves by the following means:

1. Pipeline water velocity should be kept low, typically four to five feet per second.

2. Valves which cannot be closed suddenly should be used. Gate valves or geared butterfly or spherical valves are suitable.

3. Electronic governors may be used. These do not cause changes in water velocity because the turbine operates at constant load (unless head level control changes a spear valve).

4. When using a mechanical governor or automatic emergency shutdown, jet deflectors on impulse turbines should be used to avoid sudden changes in flow.

4.13 VALVES

Valves for use on small hydro penstocks should be slow acting to avoid water hammer.

All valves are rated as to pressure, allowable water hammer, and type of service such as water, steam, or oil. Valves should always be specified as to working pressure, exposure to water hammer, and trim. Water valves will usually be specified with brass trim and this means that the replaceable wearing parts are made of brass.

Valves eventually leak at the bonnet and should be adjusted by tightening the gland nut. Eventually the packing, which is usually square cross-section asbestos, impregnated with graphite grease or synthetic wax, must be replaced.

Valves can be overhauled by firms which specialize in that trade. Valves usually last a long time, and for this reason suitably-rated, good used or rebuilt valves may be used for many applications. In non-critical applications such as intake valves, used gate valves may be a less expensive alternative to fabricating slide valves on site.

Gate valves: Gate valves have a handwheel and threaded rod which open and close an interior slide gate. Gate valves cannot be rapidly closed or opened. Gate valves should not be used to throttle flow.

Butterfly valves: Butterfly valves have a circular plate which just fits the interior bore. This plate is connected by means of a rotary shaft to an operating lever. They can be closed or opened suddenly, and have a self-serve closing action. This type of valve can inadvertently be caused to slam shut and is therefore inherently dangerous. Geared butterfly valves cannot be closed as quickly, and are frequently used.

Spherical valves: Spherical valves have an interior sphere with an opening equal to the pipeline bore. Spherical valves can be closed or opened suddenly.

Geared butterfly and spherical valves which cannot be closed quickly, are available for use on penstocks. If for any reason butterfly or spherical valves are to be used, the geared type is highly recommended.

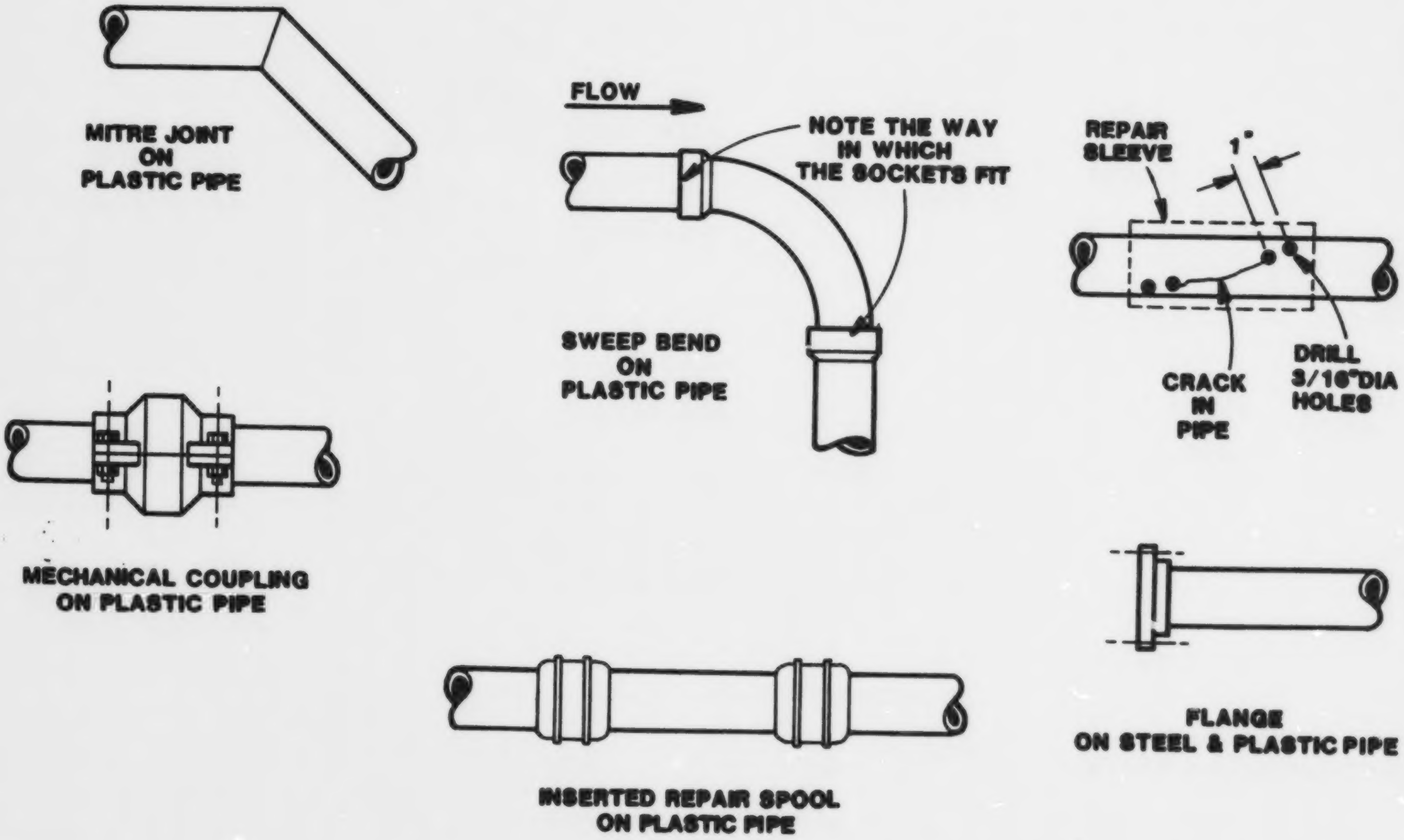
Globe valves: Globe valves have an interior plug which can be raised or lowered by means of a threaded rod and handwheel. The tortuous water path through the valve makes globe valves unsuitable as penstock valves. Globe valves can be used when the flow must be throttled or varied.

Summary

Gate valves are preferred in penstocks because of the slow closing feature. They can be supplied with electrical or hydraulic operating gear for remote control or emergency operation.

Butterfly valves are occasionally used as a means to prevent turbine runaway on Francis or propellor turbines. If used for this application, gate valves must be arranged so that they can be quickly closed to about one-third flow, and then much more slowly closed to complete closure. This may be achieved using a shock absorber or dash pot. These steps are necessary to prevent water hammer, and additional preventative devices may be necessary.

Globe valves are usually installed in such services as drain valves where efficiency is not a consideration.


FLOW
NOTE THE WAY IN WHICH THE SOCKETS FIT
REPAIR SLEEVE
1"
CRACK IN PIPE
DRILL 3/16"DIA HOLES

MITRE JOINT ON PLASTIC PIPE

SWEEP BEND ON PLASTIC PIPE

MECHANICAL COUPLING ON PLASTIC PIPE

FLANGE ON STEEL & PLASTIC PIPE

INSERTED REPAIR SPOOL ON PLASTIC PIPE

FIG.4-77PIPING DETAILS

4.14 CANALS, FLUMES AND LINED CHANNELS

Canals, flumes and lined channels should not be overlooked. One or another of these water transport systems can be economic and effective where circumstances are favorable. On many sites, water must be extracted from a stream or river and transported for some distance to a point where sufficient head can be developed. Where the gradient between the intake point and the head pond is small, any of the above methods may be less expensive and more effective than a pipeline. Flumes and channels are often used in irrigation supply systems, and may be suitable for small hydro. Allowance for local ice cover must be made in establishing the size.

Surge Towers

Surge towers prevent or at least control pressure surges and water hammer to within acceptable limits. They are an alternative to automatic turbine bypass valves, and are most often seen on medium and high head reaction turbine plants with long penstocks.

The costs of surge towers can seldom be justified for small hydro sites.

4.15 TURBINES

General

There is a number of different types of hydraulic turbines; and although there is some overlap between them, each type tends to have a distinct range of applications where it will be more economic and/or more efficient than any other type. The turbine generator unit represents a large portion of the total cost of any small hydro plant, and on sites where the owner is performing most of the labor himself, the turbine can easily become the most expensive item. Inasmuch as capital cost is so significant, and the industry so competitive, the choice of turbines or pumps tends to be directed towards turbine types which are inexpensive and simple to construct. These factors favor impulse turbines, extending their use into areas where other more expensive turbines would otherwise be the logical first choice.

Turbine Types

Impulse turbines utilize the power in a jet of water. There are three types:

Pelton
Turgo
Crossflow

Pelton Turbines

Pelton turbines have one or more specially shaped nozzles which direct jets of water into a series of split buckets mounted on the circumference of a disc. Energy in the water is extracted by the buckets which split the water jets, turning the water back on itself such as to just miss the incoming jets. The water is slowed down as it delivers its kinetic energy into the wheel, and the discharge water falls out of the bottom of the turbine.

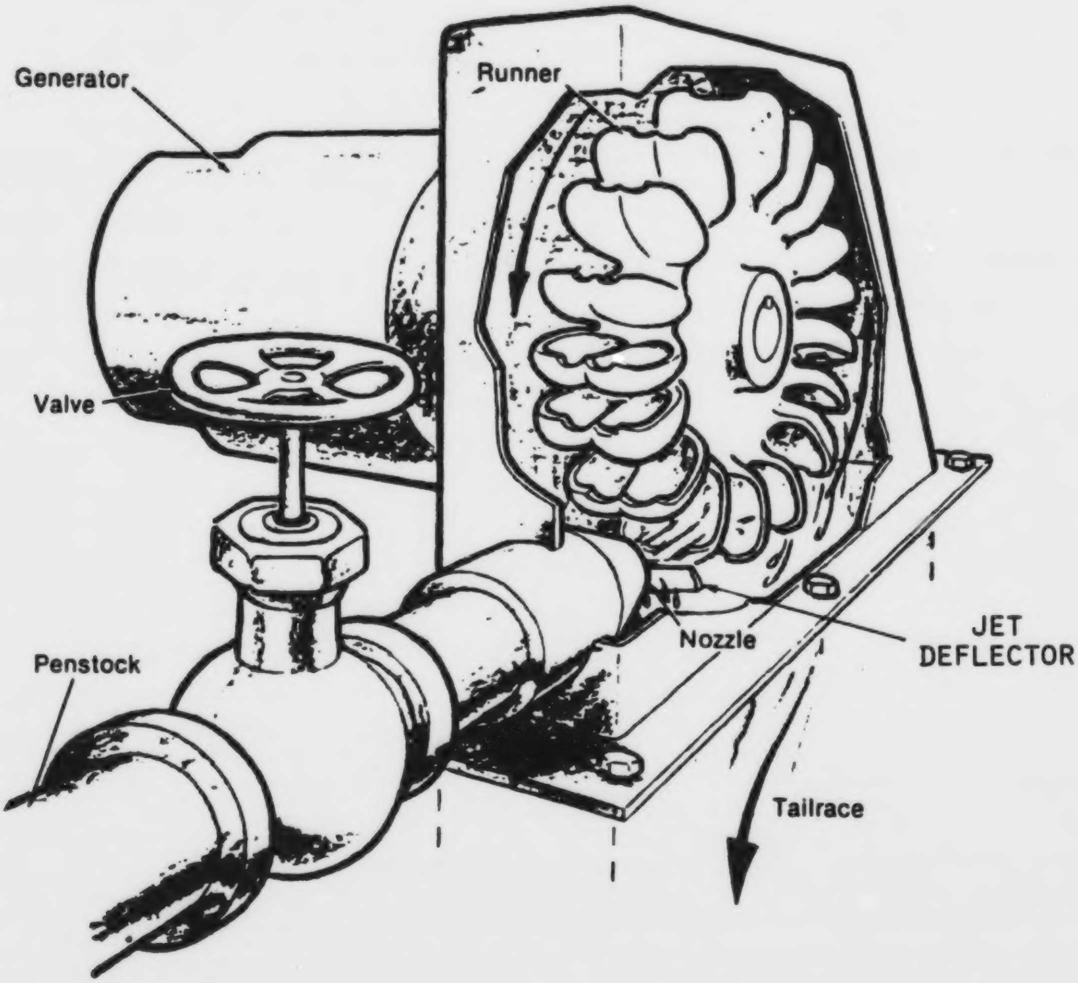

Generator
Runner
Valve
Penstock
Nozzle
JET DEFLECTOR
Tailrace

FIG 4-78 Impulse turbine (Pelton Wheel)

Pelton wheels show to advantage in small flow high head situations; the higher the head the better. Two or more jets are often used to decrease the diameter of the wheel and raise the speed. Fixed jet nozzles can be used, with a jet deflector for governing and emergency shutdown. On sites where water must be conserved, spear valve nozzles must be used (see Figure 4-79). In this case, the jet deflector can be retained as an emergency shutdown or additional governing feature.

Mechanical governors are commonly employed, and can be arranged to operate both the spear valves and the jet deflector, or in some cases, the deflector alone. An electronic load control governor needs only fixed nozzles, but if supplied with water control, spear valves must be supplied with the turbine as well.

Pelton turbines will stand up fairly well to silt and sand in the water, but the higher the head, the more care must be taken to reduce sand and silt to the minimum.

Turgo Turbines

Turgo turbines use a similar principle to the Pelton, but have larger jets. The stream of water is directed against one side of the turbine wheel where it passes through a series of curved vanes and is ejected on the side of the wheel opposite the jet. Since Turgo wheels can have larger jets than Pelton wheels, the Turgo wheels can develop more power for a given size. They can pass about three times as much water as a Pelton, and run twice as fast under comparable conditions. Turgo turbines can be provided with jet deflectors and/or spear valves similar to the Pelton, and governing action is the same.

Turgo turbines will stand up to sand and silt better than any other turbine.

The usual range of head is from 100 feet to 600 feet, although some have been used on heads as low as 35 feet.

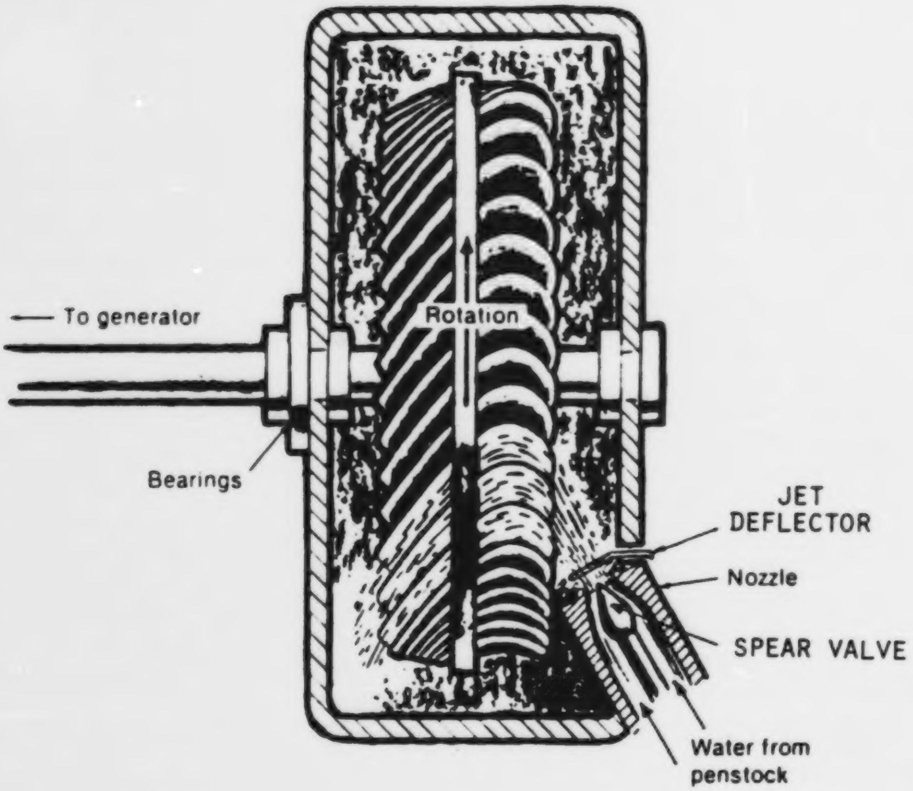


Fig 4-79 Turgo impulse turbine

Crossflow Turbines

Crossflow turbines, variously known as Michell-Banki and Ossberger turbines are a form of impulse wheel which is naturally adapted to handle a large volume of water. Crossflow turbines are therefore useful on low to medium heads of say 7 feet to 150 feet, although some have been successfully used on heads as low as three feet. The jet consists of an elongated rectangle which directs the water into a series of curved blades mounted between circular end plates.

The jet passes through the blades twice, although the power produced in the second pass is small. Some builders fit short draft tubes on the turbines for a small gain in efficiency.

The turbine jet can be divided into compartments. Usually, there are three compartments used which can be throttled independently of each other. On low loads, the turbine will use only one compartment equalling a third of the jet area, and increasing with load from two thirds to full. By such means, the turbine efficiency can be maintained at a high level throughout a considerable variation in flow. This feature can be used to optimize generation on streams with large seasonal variations, as crossflow turbines will develop useful power on about 15 percent of full flow.

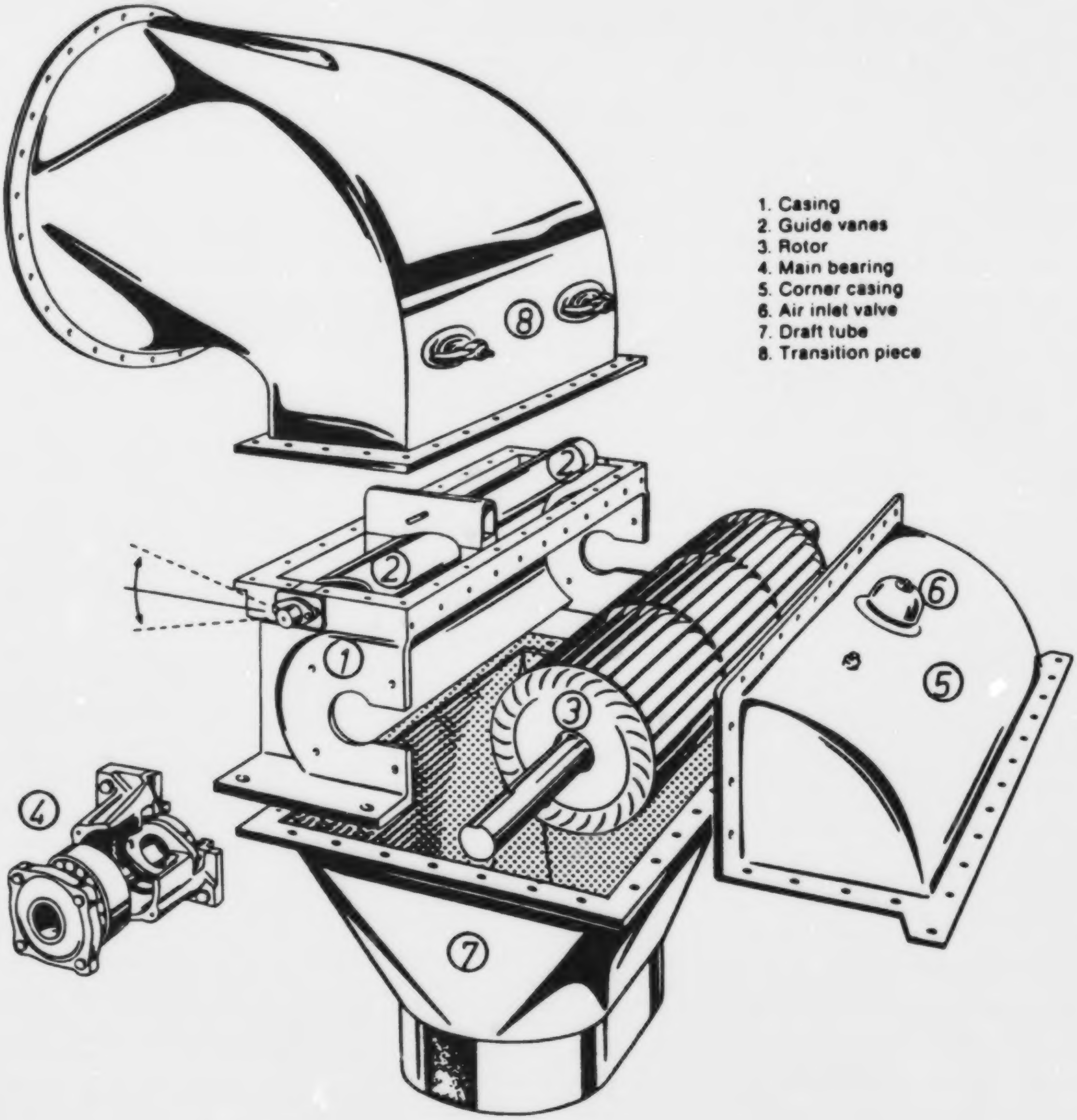

1. Casing
2. Guide vanes
3. Rotor
4. Main bearing
5. Corner casing
6. Air inlet valve
7. Draft tube
8. Transition piece
①
②
③
④
⑤
⑥
⑦
⑧

FIG 4-80 CROSSFLOW TURBINE

Crossflow turbines are fabricated from light gauge steel, which makes them vulnerable to abrasion by sand and silt. Crossflow turbines can be built for heads as high as 600 feet or so, but in such applications, the effects of sand abrasion and cavitation can reduce the life of the blades to as short as one year and cause the casing to become worn. The preferred range of head is from 10 feet to no more than 150 feet. The requirement for very clean water raises the cost of the dam and intake works, and a stillage basin or sand separator is necessary above about 50 feet of head.

Reaction Turbines

Reaction turbines use the pressure head on the system and convert that pressure to kinetic energy. The types are Francis, Propeller and Kaplan.

Francis Turbines

In larger sizes, Francis Turbines are most commonly used, especially by utility companies, in low to medium head sites. The turbine consists of a runner with blades to take in water in a radial direction, turn it through an arc formed by the blades, and discharge it axially. The runner receives water through a series of vanes surrounding the intake. This assembly of vanes, called a wicket gate, is used to control the volume of water and hence its power and speed as it enters the turbine. Francis turbines are normally supplied with mechanical governors which actuate the vanes in response to load changes. Surrounding the wicket gate assembly is a scroll case which accepts water from the penstock and distributes it symmetrically around the turbine intake. The water exits the turbine into a draft tube, which extracts any remaining energy in the water and also keeps the turbine full.

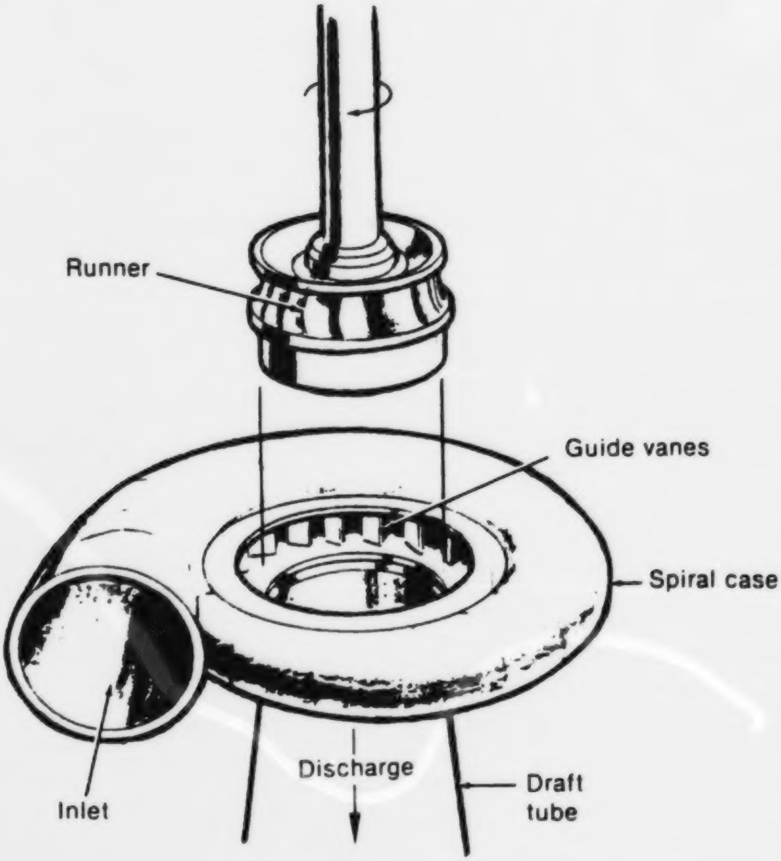
Although complicated, the Francis turbine has a higher efficiency than any other, although the peak efficiency range is quite narrow.

A disadvantage for small sites is that water flow through the Francis turbine becomes unstable at less than about 40 percent full flow, and does not operate satisfactorily on less than 40 percent full load.

Francis turbines can be installed either horizontally or vertically. Small units are usually built as self-contained, free standing units which can be bolted to the floor. These are quite site specific, and will show high efficiency only if the installation is carefully designed to suit the exact site conditions.

At one time large numbers of low head Francis turbines were installed in flumes with neither wicket gates nor scroll cases. Most of such installations were for mechanical drives, but could be used today with electronic load control.

The preferred range for small hydro is 50 feet to 200 feet although both higher and lower heads can be accommodated. Francis turbines are susceptible to wear by sand, silt and frazil ice. Small Francis turbines tend to be expensive.



INEL 2 2356

FIG 4-81 Francis reaction turbine

Propeller Turbines

The propeller turbine has characteristics which make it useful for low head applications. Operating speed is comparatively high even at very low heads. The turbine looks very much like a marine propeller, with the blades twisted through an angle from hub to tip, and having a thin aerofoil shape. The blade angle increases as head decreases. Propeller turbines are quite small in diameter for a given throughput of water. The preferred range is 10 feet to about 60 feet in small sizes. Propeller turbines have a sharply peaked efficiency curve and are essentially a fixed speed fixed load turbine, and work very well with electronic load controllers.

Axial flow pumps have been successfully used as turbines (see subsection "Pumps as Turbines").

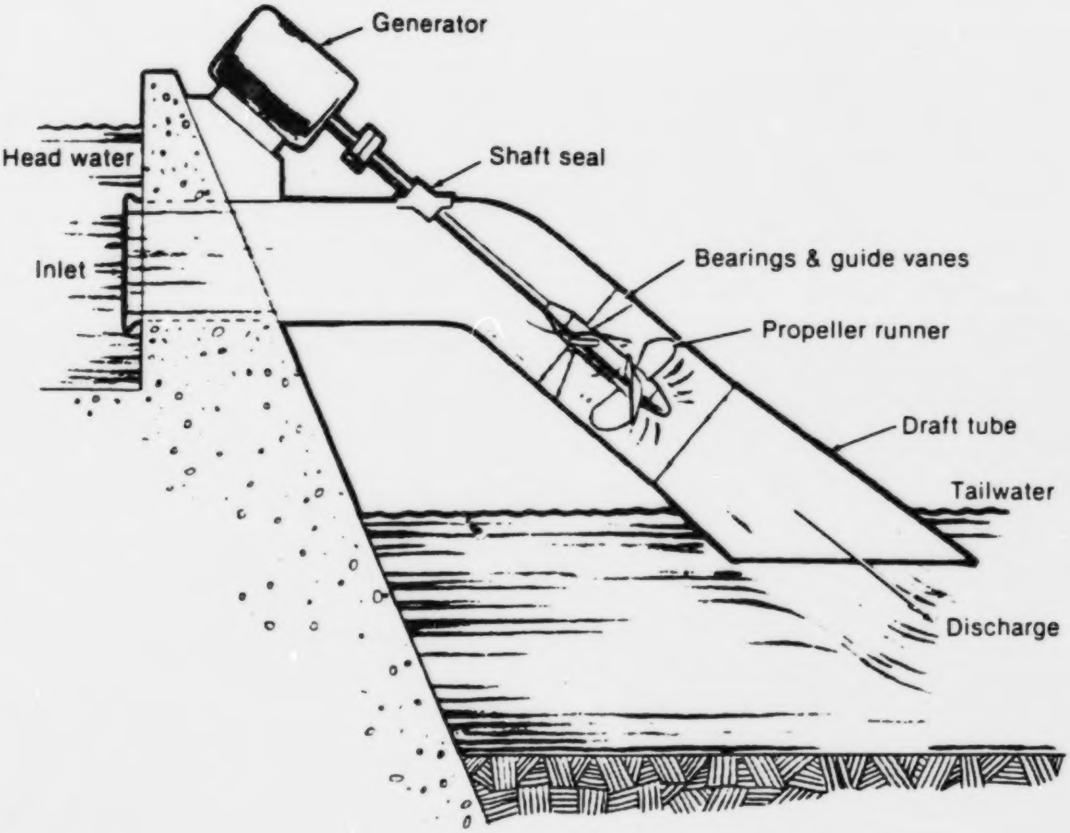

Generator
Head water
Shaft seal
Inlet
Bearings & guide vanes
Propeller runner
Draft tube
Tailwater
Discharge

Fig. 4-82 PROPELLER TURBINE

Kaplan Turbines

Kaplan turbines are a propeller turbine with adjustable blades, similar to a controllable pitch marine propeller. The blade angle can be adjusted by the governor in response to load so that the efficiency remains high at all times. The complicated blade mechanism makes the cost high.

Other Turbine Types

Axial flow, bulb turbines, tube turbines and other configurations are often used on larger sites. At least two new types of turbine are currently under development: modified axial flow and viscous friction. The continuing high interest in small hydro has brought abour a resurgence of experimental work on small turbines. Refinements in design and the production of components on numerically controlled machine tools will lead intime to higher efficiency and lower costs.

Turbine Speeds

On no load conditions, the speed of the water flowing through an impulse will be equal to the spouting velocity, which is the natural speed of water freely issuing from a jet, and is equal to:

$$V = \sqrt{2gh}$$

where V = velocity in feet per second,
g = gravitational constant, 32.2,
h = head in feet

Turbines depend upon the deflection of the water jet or current in order to develop power. If the circumferential velocity at the edge of the turbine wheel were equal to the spouting velocity, no deflection would take place and no power could be developed. Actually, a little deflection does take place, just sufficient to keep the wheel running at a speed nearly equal to the spouting velocity. This is true for all turbines, which run at about twice full load speed under conditions of no load. Full jet deflection occurs at very nearly half of the no load speed. Thus, we have a condition that at any load between zero and full load, the turbine, left to itself, would run at a speed proportional to load. The only way to control the speed is either to ensure that the load remains fixed, as in the case of electronic governors, or to vary the amount of water entering the turbine by means of a mechanical governor operating in the turbine valves.

4.16 WATER CONTROL TO TURBINE

In-line penstock valves and accessories include:

intake valve
stop logs
vacuum breaker pipe
turbine stop valve
bypass valve, or penstock drain
water supply and fire protection valve
electrically operated turbine stop valve
jet defelctor
safety devices
wicket gates

For any given penstock, not all of these will be used, but the following conditions must be met:

(a) water shut-off at the intake,
(b) water shut-off at the turbine.

Other features may become necessary according to the layout of the penstock.

Stop Logs

In addition to sliding gates, stop logs are often used on large intakes or canals. They consist of a series of square timbers which are dropped one by one into slots in the concrete structure ahead of the sliding gates. Stop logs enable maintenance work to be carried out in the sliding gate and may be used in the event that the sliding gate jams or is blocked open by debris.

The intakes referred to in this manual, are not very large, and therefore the stop logs could be replaced by one piece of solid timber or a metal gate. Sometimes fine trash racks are placed between the stop logs and the gate. Canal type gates are occasionally used. See section on Intakes for further details.

Vent Pipe

Vacuum breakers consist of a vertical standpipe located downstream of the intake valve. The purpose of the vacuum breaker is to prevent the occurrence of a vacuum in the penstock when the intake valve is closed. If a vacuum breaker is not provided, the water receeding down the penstock will create a vacuum which is liable to collapse the pipe. Plastic pipe and large diameter steel pipes are very vulnerable to collapse. The vacuum breaker pipe should be about 25 percent of the penstock diameter, and must be higher than the intake level.

Turbine Manual Stop Valve

The turbine manual stop valve is used to shut down the plant for maintenance or in emergency circumstances. The proper type to use is a gate valve, which cannot be shut quickly, because slow closure is necessary to prevent water hammer in the penstock. Ball valves and butterfly valves are sometimes used, but either one can be closed too quickly. A butterly valve will take over when partly shut and will slam, probably causing damage to the penstock. Geared ball and butterfly types are safe, as the gear ratio prevents sudden closure.

Turbine stop valves may be located either inside or outside the power hourse, and a good argument can be made for either location. If the turbine runs away, you may be glad you placed it outside. If installed outside, they save space; however, they must then be insulated. Wherever located, the valves must be flanged to a length of steep pipe, the other end of which is imbedded securely in the thrust block.

Bypass Valve

Occasionally, the turbine discharge will be needed for irrigation of other use, and must be available even when the turbine is shutdown. In this case, a branch pipe must be installed at least ten pipe diameters ahead of the turbine valve.

The bypass can be used to maintain a good flow in the penstock during winter shutdown, and can be used to flush out the penstock. If opened before stopping the turbine, it will prevent water hammer. A gate valve or globe valve may be used.

Turbine Drain

Water in the penstock between the turbine and stop valve will usually drain out through the turbine. If not, install a half-inch valve and drain the pipe at the lowest point.

Water Supply or Fire Valve

Valves for water supply of fire services can be installed on the penstock as required. These valves should not be screwed into the penstock, but should be installed on a flanged stub welded to the penstock. All such valves should be at least ten penstock diameters above the turbine valve. These service pipes should be at least two feet apart.

Electrically Operated Turbine Stop Valves

Electrically operated turbine stop valves can be closed automatically by action of the emergency shutdown protective circuits. They are driven by a d.c. motor from a storage battery or hydraulically or by penstock water pressure. Usually 12 or 24 volts are used, but other voltages are available. This type of valve when used is always installed in the power house, and may be operated by hand, if necessary. These valves tend to be expensive, but are necesary on remote plants, and should be considered for any hydro plant. It might only operate once to pay for itself.

Safety Devices

Many systems call for automatic bypass valves, especially on reaction turbine plants where extreme load swings may cause pressure waves in the penstock. They are designed to bypass a certain volume of water past the turbine for a specific period of time and are quite common on reaction turbine installations where surge towers cannot be used. Other designs utilize surge chambers on surge towers, but the system to use depends upon the layout and characteristics of the penstock and power plant. Bypass valves or surge towers are not usually required on low head plants.

Pressure relief valves are occasionally installed in high head penstocks. where the valve is similar to a springloaded or servo-operated safety valve, set to open at a particular pressure. Relief valves are a last line of defence for the penstock, and will generally be installed only when water hammer in the penstock may otherwise reach dangerous pressures.

Impulse turbines for very high heads, say about 500 feet, should always be fitted with jet deflectors and possibly automatic bypass valves.

High pressure penstocks must be checked out by a professional, as the forces involved are very high and failure can be catastrophic. Bursting discs have been installed on some plants, but as a rule, they are not fast enough to serve any real purpose.

How Much is Enough?

You will need an intake valve, vacuum breaker pipe, turbine stop valve, penstock drain valve, and bypass. On very high head installations, over 500 feet you may consider an automatic pressure relief valve but you should use jet deflectors as well.

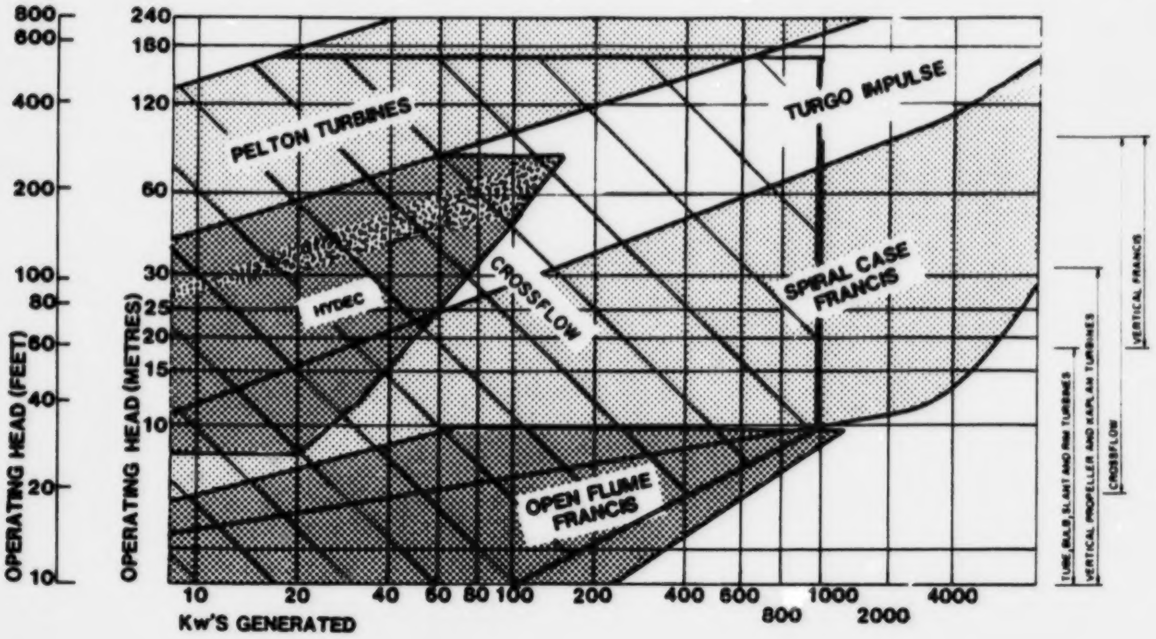


FIG.4-83RANGE OF TURBINES

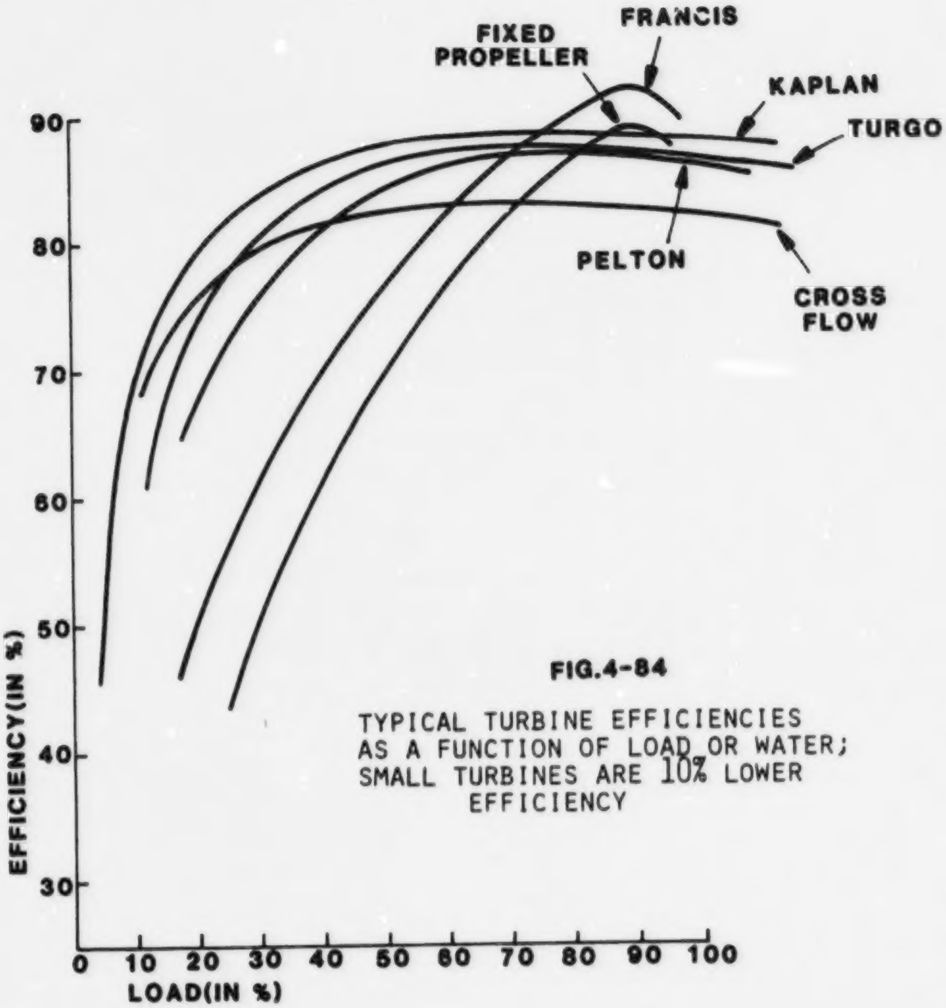


FIG.4-84

TYPICAL TURBINE EFFICIENCIES
AS A FUNCTION OF LOAD OR WATER;
SMALL TURBINES ARE 10% LOWER
EFFICIENCY

Safety Considerations

The penstock contains a very large quantity of potential energy which can cause extensive damage and personal injury should it get out of control. You should always use caution when dealing with a penstock under pressure; when working on the penstock or penstock supports, drain it. Sudden hydraulic shocks, such as occur when valves are shut too quickly, send pressure waves up and down the pipe. These can be severe enough to cause the pipe to jump off the cradles and to rupture the pipe. (See paragraph on water hammer.)

Caution: All valves leak when worn, and intake slide gates leak more than most. Therefore, when the penstock has been drained for maintenance work, be sure to leave the bypass valve open. Otherwise, the penstock will slowly fill up, constituting an unsuspected hazard.

4.17 MECHANICAL GOVERNOR

The speed of hydraulic turbines, in common with other types of prime movers such as diesel engines and steam turbines varies inversely with the load. Speed variation is undesirable in certain applications, such as the generation of a.c. current, because constant speed is necessary to provide 60 Hz.

Mechanical governors contain two main elements, a flyball device to sense speed changes, and a device to operate the turbine control valves.

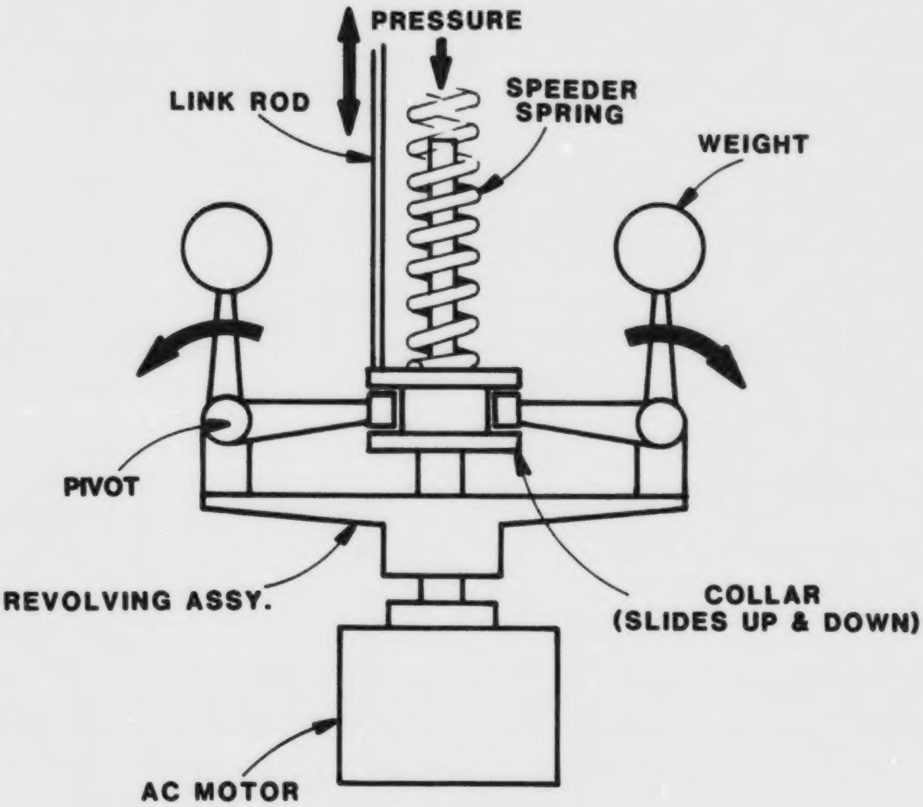

PRESSURE
LINK ROD
SPEEDER SPRING
WEIGHT
PIVOT
REVOLVING ASSY.
COLLAR (SLIDES UP & DOWN)
AC MOTOR

FIG.4-85FLYBALL GOVERNOR

When rotated by the a.c. motor, the weights move outward to assume a balance position between the centrifugal force of the weights and the spring pressure. Any change in speed will cause motion which can be detected, amplified, and applied to the turbine controlling elements. Extremely small variations in speed can be detected, and the governor will take corrective action if the speed varies by more than plus or minus 0.1 percent of rated speed. The governor continually responds to load changes, making smooth adjustments and resettling itself for each new position by means of a feedback linkage, known as restoring gear. You should study carefully the instruction manual which you will receive with your governor.

The most common mechanical governor is the Woodward (Woodward Governor Company, Rockford, Illinois) type UG, which is normally supplied with an hydraulic pump and servomotor for hydro application. This unit is essentially the same as the governing unit used on large scale hydro plants. It is a precision made, highly accurate and reliable unit which seldom requires repair. Mechanical governors are unaffected by electrical surges or spikes which can damage electronic units. Woodward UG governors are more expensive than electronic load control devices, which are limited to larger sized units over about 75 kW to 200 kW.

The mechanical governor usually incorporates the following features:

(a) suitability for automatic synchronizing, and adaptability to either load or frequency control;

(b) adjustable limit called "gate limit" to positively limit the maximum servomotor position, adjustable between 0 percent and 100 percent. This controls the amount by which the turbine control valve may be opened;

(c) permanent and temporary droop settings, necessary when paralleling;

(d) adjustable operating time for the servomotor. This is an important feature where water starting and/or water hammer must be considered;

(e) availability of various accessories, such as a shutdown solenoid for emergencies, a speeder motor for remote control, tachometer and speed switches.

Droop

There must be a slight speed change in order for the govenor to react. This is called droop and the amount of droop can be adjusted. On stand alone plants, droop is usually set at zero. When paralleling with another hydro plant or with a diesel, droop settings of each governor must be adjusted to control the load pick-up point of one machine versus another.

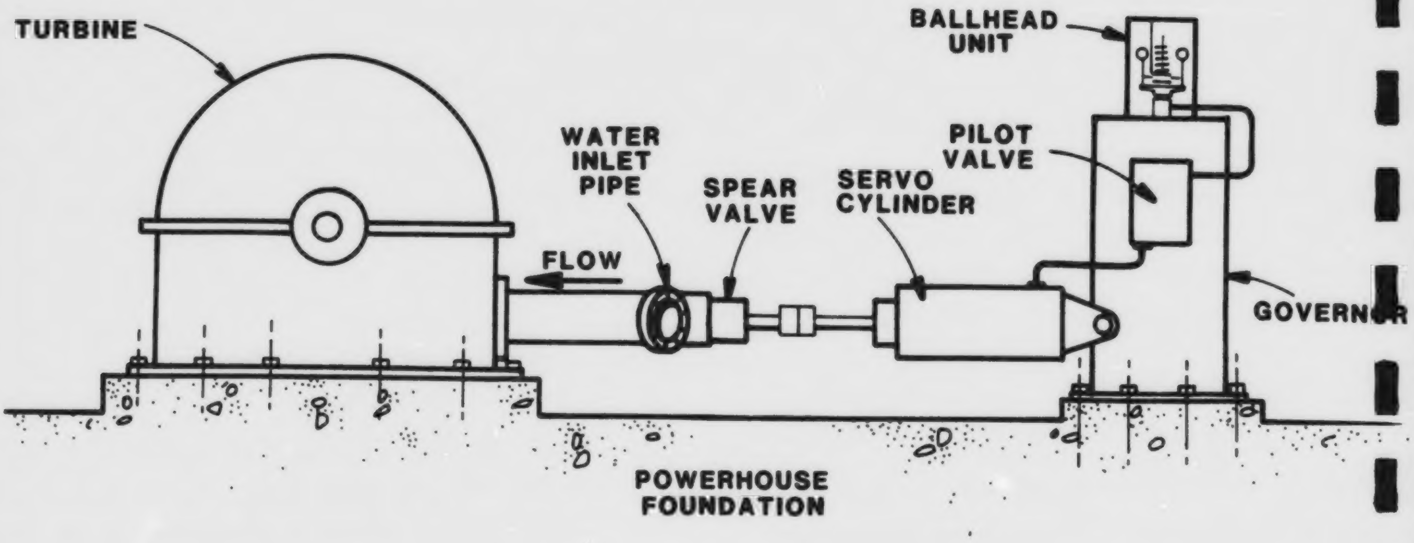


FIG.4-86MECHANICAL GOVERNOR LAYOUT

Figure 4-86 shows a typical impulse turbine installation using mechanical governor.

4.18 ELECTRONIC LOAD CONTROL GOVERNORS

Load control governors are an alternative to mechanical governors, and operate on a different principle. They control the speed of the turbine by maintaining constant load on the generator. This is done by continuously comparing the generator output frequency to an internal frequency standard, usually a quartz crystal clock circuit. Deviations from standard clock frequency are detected and acted upon. Low generator frequency corresponds to generator overload, while high generator frequency corresponds to under load. An internal control circuit causes solid state relays to switch loads on and off in order to control the load on the generator and hence control the frequency. The load controlling system also contains a substantial governing load which is supplied from a variable voltage source in order to fine tune the system load and frequency.

This governing system depends upon having a fairly wide selection of loads which can be ranked in priority. Load controllers are set up to favour certain priority loads, such as lighting and domestic appliances, while other loads such as water heaters or space heaters will only be supplied when energy is available for them. The extent and duration of frequency excursions during load switching are typically a few hertz either side of 60 Hz, and lasting not more than one to three seconds.

Basic Load Control System

Load controllers are entirely solid state electronic devices, and may be advantageous for small plants. There are no mechanical or hydraulic controls. Load controllers maximize the production of energy while avoiding the high cost, relative to plant size, of elborate mechanical governors. However, the cost of installing and arranging circuits and wiring for non-priority loads and energy loads increases with plant size. At some point, the mechanical governor turns out to be simpler and more economic. Depending upon plant characteristics, this point will be reached somewhere between 75 kW and 200 kW, although circumstances other than capital cost may determine the choice of governor.

Advantages of Electronic Governing

1. Such a system is less costly than mechanical governors for small plants.
2. Load controllers maximize energy available from the turbine generator.
3. Load controllers will often enable a smaller turbine generator to be installed since peak load and hence generator size can often be reduced.
4. Load controllers avoids water hammer problems since the flow of water is not controlled.
5. Load controllers can easily be modified to suit particulars of the loads.
6. Response time is superior to mechanical governors.
7. Load controllers can easily be installed on any small site, and can be retrofitted.

Disadvantages

1. Load controllers do not economize on water (unless a water control module is added).
2. Load controllers impose continuous full load conditions on the turbine generator and may shorten its life.
3. Load controllers require the installation of non-priority loads and load sinks which can become inconvenient and expensive for larger plants.

4. Electronic failure can lead to turbine runaway.

5. Utilizing all of the energy all the time is not always convenient, so a certain amount of waste is inevitable.

6. The electronic equipment is specialized and complex. Site repairs may be difficult or impossible.

Diagram

The following diagram shows a basic wiring for a load management system.

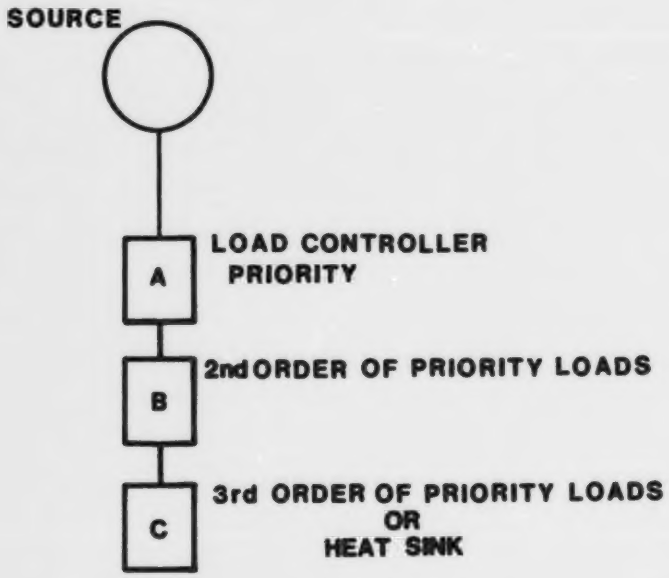

SOURCE
A
LOAD CONTROLLER
PRIORITY
B
2nd ORDER OF PRIORITY LOADS
C
3rd ORDER OF PRIORITY LOADS
OR
HEAT SINK

FIG.4-87 LOAD MANAGEMENT SYSTEM (BASIC WIRING)

Typical Priority Loads; Country Farmhouse

High Priority: (always available)

- lighting
- refrigeration
- deep freeze
- well pump
- kitchen equipment
- convenience receptacles
- block heaters
- furnace fan
- radio/tv/stereo
- workshop equipment
- barn lighting
- security lighting
- electric stove

Medium Priority Loads (usually available)

- water heater, element 1
- greenhouse heater, 2 or more
- space heater, 1
- clothes dryer

Low Priority Loads (usually available only at night)

- water heater, element 2
- space heater, 2
- space heater, 3
- energy sink

Priority loads would always be available, along with medium priority loads most of the time. Low priority loads would be available only at night in winter when domestic loads are at a minimum. During the summer, the energy sink would be used instead of space heating loads. The above scheme could be carried by a 10 kW generator equipped with an electronic load controller. One load must be arranged to serve as the governing load for fine tuning of the frequency. This could be a large single load, for instance the greenhouse heaters, which would be supplied from the variable voltage unit in the load controller. The load on the greenhouse heaters would then vary according to how much extra load is needed to control the generator frequency. When domestic load is high, greenhouse heat would be minimal. Conversely, when domestic loads are low, greenhouse heat would be maximum.

It is important that all heating appliances are not thermostatically controlled. Loads can be independently switched on or off according to seasonal requirements, but sufficient load must be available at all times to fully load the generator. This requirement sometimes calls for the installation of an energy sink to waste away excess energy such as might occur during the summer. Energy sinks usually consist of a number of immersion heaters installed in a tank, and penstock water is circulated through the tank to carry off the surplus heat. Energy sinks are a means of getting rid of excess energy which cannot be used elsewhere.

Electronic Load Control With Water Usage Control

In certain situations, economizing on water use may be necessary. This need may arise on sites where low winter or summer water flows may not be sufficient to maintain full load on the generator. Also, some sites depend on the storage of water to carry the plant through daily load peaks and cannot provide continuous full load power output. Either of these conditions can be met by combining the features of the basic electronic load controller with a simplified mechanical water control device on the turbine. A water level indicator sending unit is installed at the intake to measure water level.

The load controller can be programmed to minimize the amount of energy used by the load controller governing load (governing margin load). This is a useful feature in plants having water storage capability, especially when the governing load is a high proportion of the total load. If the water level indicator is installed in the reservoir, non-priority loads will be switched off until the reservoir fills, and the amount of water used by the turbine will be reduced accordingly. When the reservoir is re-filled, non-priority loads can be switched on. The same principle can be used on sites which have a seasonal low. The falling level at the intake can be made to cut back generation by reducing the low priority loads and reducing the water flow. In reservoir plants, the sum of the priority loads must be related to the volume/time capability of the reservoir, and peak topping may be necessary. A wide range of techniques and hardware is available to tailor each application for maximum efficiency and convenience, and coordination with the manufacturers is recommended.

On small hydro plants utilizing electronic governors, little or no custom engineering is required, because the governing action is not affected by site dependent characteristics such as length and size of the penstock. Load control governors are designed to perform three jobs in a hydro-electric installation: govern speed by load control; move power around upon demand so that the power available is being used to its maximum usefulness (this is known as load management); and prevent overloading of an hydro-electric plant by shedding loads at peak demand periods or during low water (this is known as peak demand control).

Small System Operation: Peak demand control becomes most important on systems that have only a small generator connected, since the total load could exceed the output of the generator. In extreme cases, only loads that must always be available (e.g. inside lights) would be connected directly to the generator. All other loads would be connected to relays so that they will be turned off if the power is needed elsewhere.

Large System Installations: In a system that has a relatively large generator, the connected load is not so likely to exceed the output of the generator. Hence peak demand control becomes less important. All user loads may be connected directly to the generator without fear of overloading. In addition, low priority loads that can be controlled by the governor must be installed to use up excess generation.

Long Term Trend in Large Systems: Subsequent to the initial installation, the return on the investment as well as the usefulness of the installation will be maximized by finding additional useful purposes for surplus generation. Hence load management tends to become more important as time goes on.

Small System Example: A 5 kW generator supplies a single household. The user has connected the loads as follows:

DEMAND - lights, convenience outlets (maximum load 5 kW, minimum load 0 kW)

MAIN CONTROLLER - 3 kW of hot water heating (large tank) switches to a 3 kW baseboard heater when water is at maximum temperature.

Note the following with regard to this sample installation:

1. Loads that must be available on demand such as lights, radio, television, and toaster, are directly connected to the generator, but these loads never exceed a total of 5 kW at any one time. They thus provide peak demand control by avoiding overloads.

2. The loads connected to the relays in this example never exceed 2 kW per step (two/thirds of the 3 kW main Governor load).

3. The lesser priority loads are connected to the relays in order of priority, and any of these loads may be turned off if there is insufficient power.

4. The total dependable (i.e. always available) load connected to the Load Control Governor system must exceed the maximum surplus power available from the generator to avoid overspeed. Note that this does not prohibit some or all loads connected to the relays from being interrupted at times. Large generators will generally need more assured loads to soak up surplus power, while small generators will allow more flexibility in the type of load connected to the relays.

5. The uncontrolled loads connected to a system should not exceed the available power from the generator, unless the user is willing to monitor the generator for possible overload conditions.

One of the principal benefits of the electronic governor is the wide variety of options available, which enables it to be tailored to suit virtually any system. It is advisable to discuss your requirements with a manufacturer in order to obtain the most appropriate equipment for your particular system. Modifications can be provided later to suit changed conditions. You should study carefully the operating manual which you will receive with your electronic governor.

4.19 TAILWATER

Tailwater is the elevation of the turbine discharges.

Impulse Turbines

In order to maximize the useful head, the turbine discharge must be as close to the tailwater level as is reasonably possible. The height chosen must take into account rising water levels during runoff and flood conditions. Also, an allowance must be made for the slope of the discharge chute. It is therefore very important to establish the flood water level at the power plant location, particularly on low head units, where available head must be maximized.

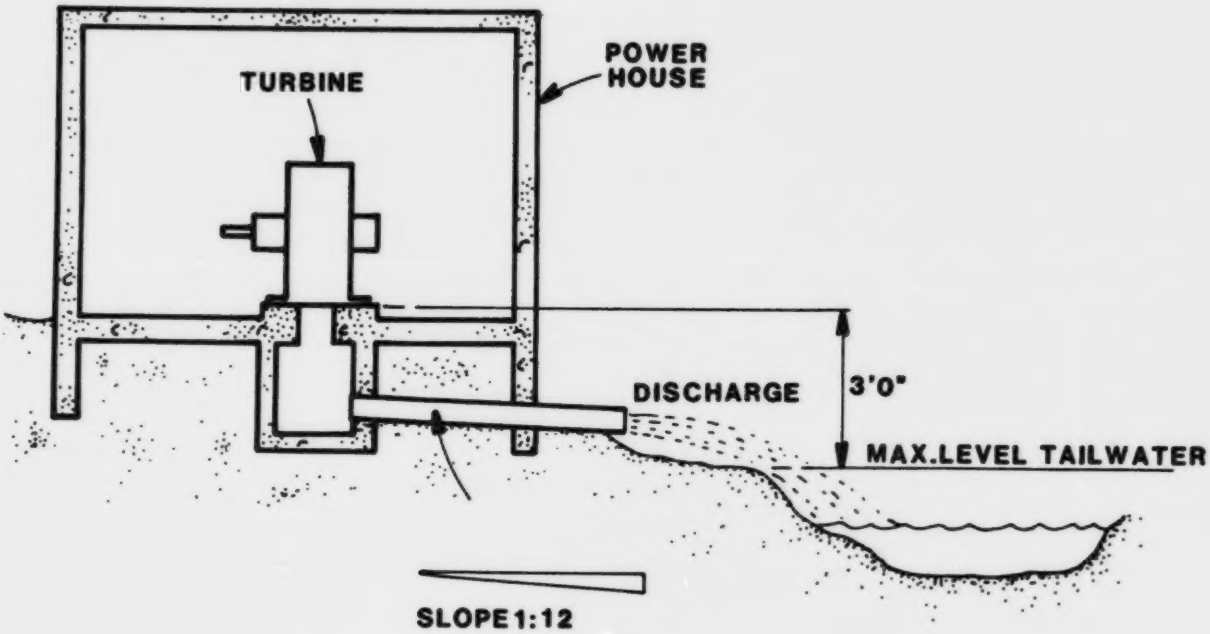


FIG.4-88HEIGHT ABOVE TAILWATER(IMPULSE TURBINE)

Reaction Turbines

Tailwater level for reaction turbines is more critical than for impulse turbines, because as floodwater level rises, less suction head is available on the draft tube (see Figure 4-__). In certain cases involving Francis and propellor turbines, a significant loss of power will accompany high flood levels, which act to reduce the head. On large plants, tailwater curves for predicted high water levels must be drawn, and from this data, the turbine setting and draft tube arrangements can be designed. Fluctuating tailwater will normally occur when the plant is located on streams or rivers. On lakeside power plants, tailwater variation may be minor while on tidewater plants tidal variations may have a serious effect. On very small, medium head reaction turbine plants, tailwater level can often be fixed by means of a sump or box culvert below the turbine discharge. This arrangement results in some potential loss of head, but is a practical alternative which avoids a great deal of professional hydrology.

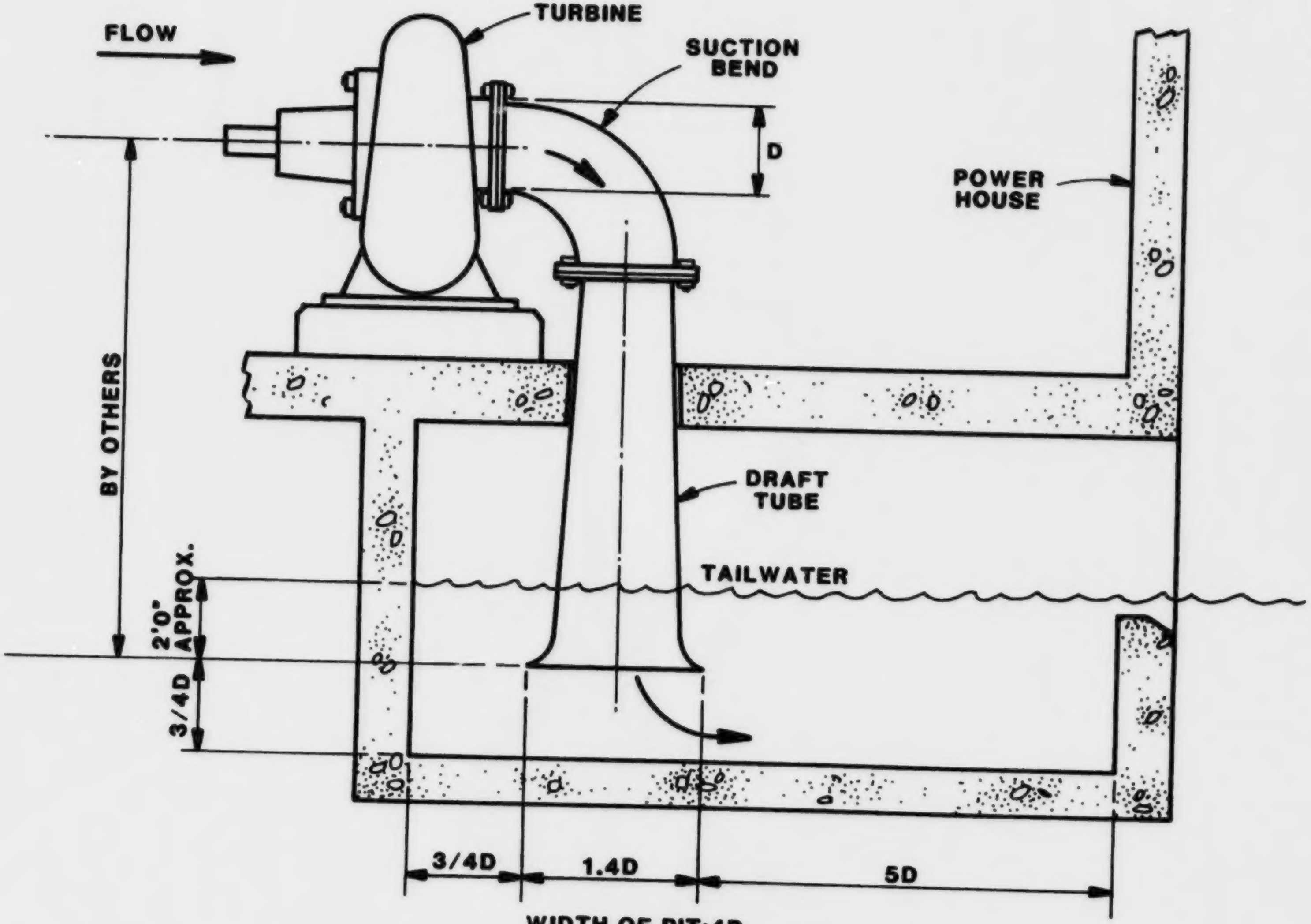

FLOW
TURBINE
SUCTION BEND
D
POWER HOUSE
BY OTHERS
DRAFT TUBE
TAILWATER
2'0" APPROX.
3/4D
3/4D
1.4D
5D
WIDTH OF PIT:4D

FIG.4-89FRANCIS TURBINE DRAFT TUBE

Discharge Water Velocity

The usual discharge velocity in the chute or culvert is two feet per second and the chute or culvert can be sized accordingly. When migratory fish must be considered, the discharge velocity should be reduced to 0.5 feet per second to prevent attracting fish into the tailrace. On impulse turbine plants, if possible, elevate the discharge end of the culvert so such that fish cannot enter it. On some reaction plants, it may be possible to fan out the discharge as it approaches the stream or to provide screens of some sort.

Pipe dia. inch.	1	2	3	4	5	6	Velocity Ft/Sec.
8	--	1.7	1.1	1.4	1.8	2.1	CFS
		3.3	7.5	13.3	20.7	30	Slope
10	--	1.1	1.6	2.2	2.7	3.3	CFS
		2.5	5.6	9.9	15.5	22.3	Slope
12	.79	1.6	2.4	3.1			CFS
	.48	1.9	4.4	7.8			Slope
15	1.2	2.5	3.7	4.9			CFS
	.36	1.4	3.2	5.8			Slope
18	1.8	3.5	5.3	7.1			CFS
	.28	1.1	2.5	4.5			Slope
24	3.1	6.3	9.4	12.6			CFS
	.19	.77	1.7	3.1			Slope

Table based on Manning's N = 0.013 (average).

CFS = cubic feet/second
Slope = feet per 1000 feet

Table may be used for calculating the size of discharge pipes, etc., flowing full.

For open top chutes find the pipe size (2 CFS) and slope from above. Then find area of pipe and multiply by 4. The necessary slope is quite small, so that an arbitrary slope of 1" in 10 feet is convenient to build and will give good results.

4.20 DRAFT TUBES

Draft tubes are used with reaction turbines, such as the Francis and propeller, as a means to limit cavitation while at the same time increasing the useful head. Design of the draft tube is far from simple, and involves among other things, the type and specific speed of the turbine, geographical elevation, and expected variations in the tailwater level. The size, shape, and length of the draft tube are determined by the turbine builder, who also determines the dimensions of the discharge pit.

On small reaction turbines, the draft tube can be of welded steel construction, and is usually considered to be a part of the turbine contract. Many different types are available to suit various plant layouts. As a rough guide, the length of the draft tube will be within the range of one to five feet, to eighteen feet depending on the turbine and site conditions.

4.21 PUMPS AS TURBINES

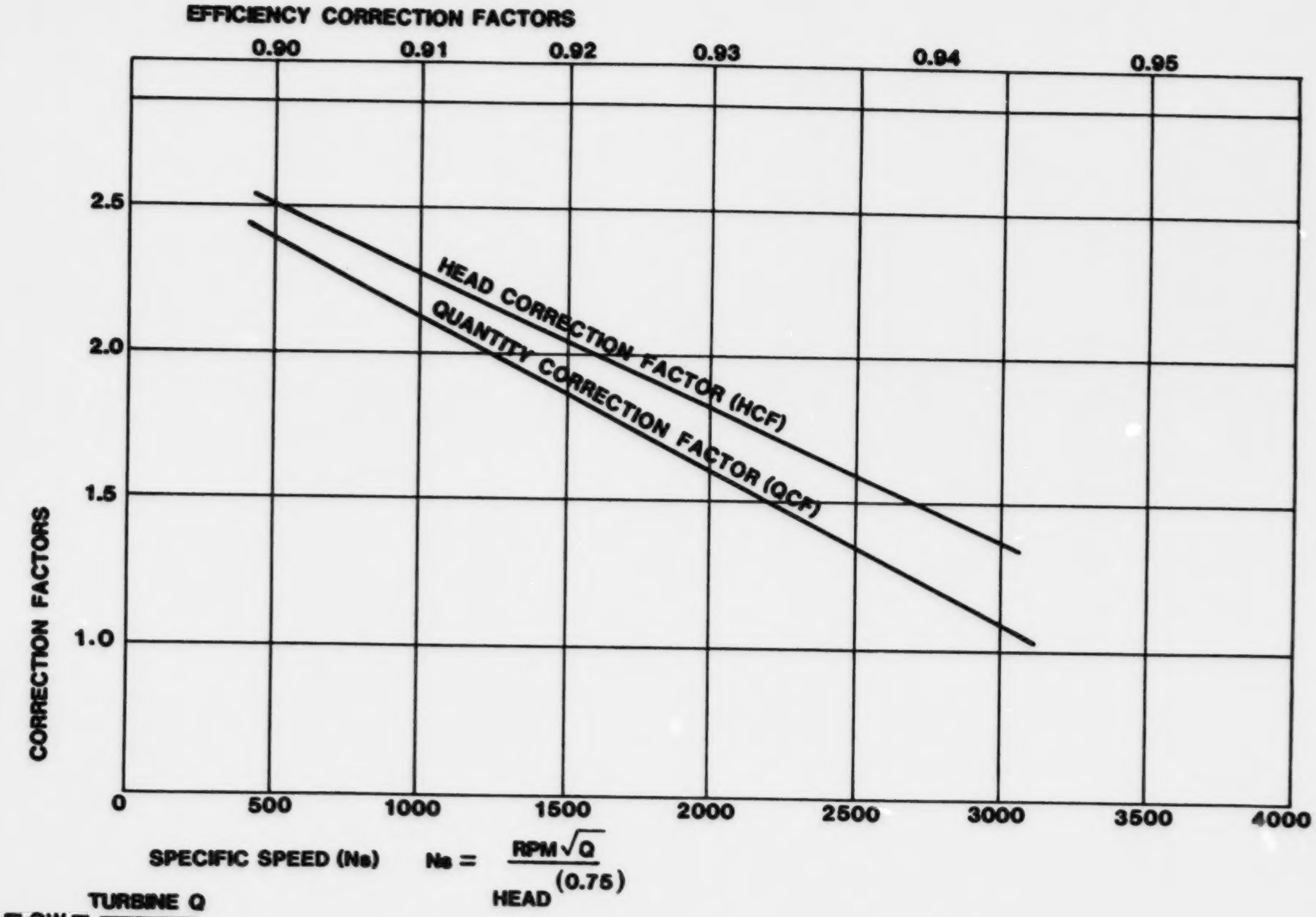
Centrifugal pumps may be used as turbines where low cost is paramount and efficiency a lesser consideration. Pumps and turbines have no speed regulating devices, so that speed will change considerably on varying load. When the load can be held constant by means of an electronic load controller, the pump can be made to operate at constant speed. A valve must be installed well upstream of the pump, as some adjustment of flow may be necessary to match the pump horsepower to the generator full load torque. An alternative is to install a bypass pipe around the turbine. The bypass valve can be used to "trim" the pump speed. You should carefully evaluate the lower cost of the pump against loss of energy due to lower pump efficiency. You may find that an efficient turbine will pay back the difference in cost within a few years.

Most of the larger pump manufacturers can now offer the correct pump when given the useful head and power requirements. This is by far the safest and easiest course, since attempting to select a pump by guesswork will usually lead to disappointing results. Most pump builders will supply impellers specifically designed for use as turbines. These impellers are quite efficient at rated rpm and flow, although not quite as efficient as turbines. Pump manufacturers select the pump using pump curves, together with application data. For high efficiency and adequate power output, this selection must be made carefully by technicians familiar with the manufacturer's product line. However, there is nothing to stop you from obtaining the necessary pump descriptions from a manufacturer, and then shopping around for a good used pump of similar size and type.

To get the pump to work as a turbine, the head and flow volume must be increased, assuming that the rated pump speed is retained.

		Conversion Factor	
Head	Specific speed	Head	Flow, CFS
High	below 1000	2.2-2.5	2.1-2.4
Medium	1500-3000	1.2-2.1	1.1-1.8
Low	3500-10000	1-1.2	1

To obtain the correct pump rating, divide your head and flow by the factors given above. (See Fig. 4-90.)



$$\text{PUMP FLOW} = \frac{\text{TURBINE } Q}{\text{HCF}}$$

$$\text{PUMP HEAD} = \text{TURBINE } H \div \text{HCF}$$

FIG.4-90CORRECTION FACTORS-USING A PUMP AS A TURBINE

Example:

Flow 2 CFS, head 90 ft

This would be near the high end of the medium head correction factors; use a flow factor of 1.8 and a head factor of 1.9.

Thus, pump rating becomes:

$$\text{rated head} = \frac{90}{1.9} = 47 \text{ ft}$$

$$\text{rated flow} = \frac{2}{1.8} = 1.11 \text{ CFS, or } 498 \text{ U.S. GPM}$$

A pump rated for 47 ft head and 500 U.S. GPM would suffice.

$$\text{Horsepower} = \frac{Q\ h\ e}{11.81}$$

$$= \frac{2 \times 90 \times 0.60}{11.81} = \underline{9.14 \text{ HP}}$$

Note: Use site flow and head in this calculation. To convert CFS to U.S. GPM, multiply by 449.

Efficiency varies lot with size, type, and manufacturer. A figure of 70 percent is commonly used for pumps running as turbines: if the pump is selected by a pump manufacturer, efficiency can be much higher.

Turbine performance with standard pumps deteriorates rapidly when operated more than about 15 percent above or below the pump's rating; cavitation is also more likely to occur. Many types of centrifugal pumps are available, but many are not suitable for use as turbines. Avoid pumps built to handle fluids other than water, crudely made pumps, so called "turbine pumps" and any others with odd looking impellers.

Draft tubes can be used with pump turbines, but should not be pushed to maximum effect because excessive suction head could induce cavitation. Check with the manufacturer. The draft tube should be coned out gradually over its entire length with a flare at the end. (See Figure 4-80)

The usual range of head for pumps as turbines is from 6 feet to 500 feet or so. Multi-stage pumps can be used, but the application is highly specific and must be done by the pump builder.

Maintenance

Pumps should be carefully aligned and periodically checked for bearing wear and end float. Some pumps have balancing discs for hydraulic purposes. When these pumps are operating, ensure that the supply of balance water runs freely. Inspect for signs of corrosion, erosion, and cavitation. Check tightness of the impeller on the shaft, couplings, etc. Some pumps have an internal wear ring. Clearance here should be very small. Where possible, obtain maintenance data from the manufacturer, or refer to the pump maintenance handbooks which are available.

Figure 4-92 shows the range of standard pumps as turbines in head and output. Figure 4-93 is a characteristic curve for one pump running as a turbine.

Do-It-Yourself Notes

Used equipment dealers and scrapyards are a reasonably good source of used pumps, but you will often need to do repairs to the bearings, shaft, and seals. You should be sure that the impeller is in good condition. Spare parts for pumps are normally quite easy to obtain, and there is a wide choice of firms who will repair pumps. You would be wise to purchase a 'brand name' pump with intact nameplate, as your chances of obtaining the pump application curve from the dealer or manufacturer are then far better.

New off-the-shelf pumps are readily available from a wide choice of dealers. Cost savings over an equivalent turbine are substantial, up to 2:1. Dealers can supply application curves, but will usually call for a review by the factory applications engineer prior to settling on the correct pump. A well designed pump usually makes a good turbine. The efficiency will be somewhat less in the turbine mode, because of the effects of reversed flow.

Operating experience using pumps as turbines is accumulating, and as yet no significant technical problems peculiar to pumps or turbines have arisen. Downtime for maintenance and repair is favorable.

Since the normal pump rotation will be reversed when operating in the turbine mode, precautions must be taken. Pumps often have threaded shaft assemblies. The nuts should be replaced with Nyloc or other self locking nuts. Thrust load is also reversed, so occasionally one or both bearings must be turned around on the shaft or a separate thrust bearing installed. On vertical pumps, the thrust load and impeller weight are often borne by the electric motor bearings, so new bearing assemblies may be necessary for turbine use.

There is much disagreement between conversion factors, and any proposed method for selecting pumps as turbines has an element of uncertainty. Manufacturers have sufficient data and operating experience to overcome this uncertainity. On a practical level, it is possible to install the pump and operate it at no load. Centrifugal impeller pumps will run at between 120 percent and 140 percent of turbine full load speed, while low head and propeller pumps could run at up to 220 percent. The speed of a pump is very difficult to estimate when the application curves are not available.

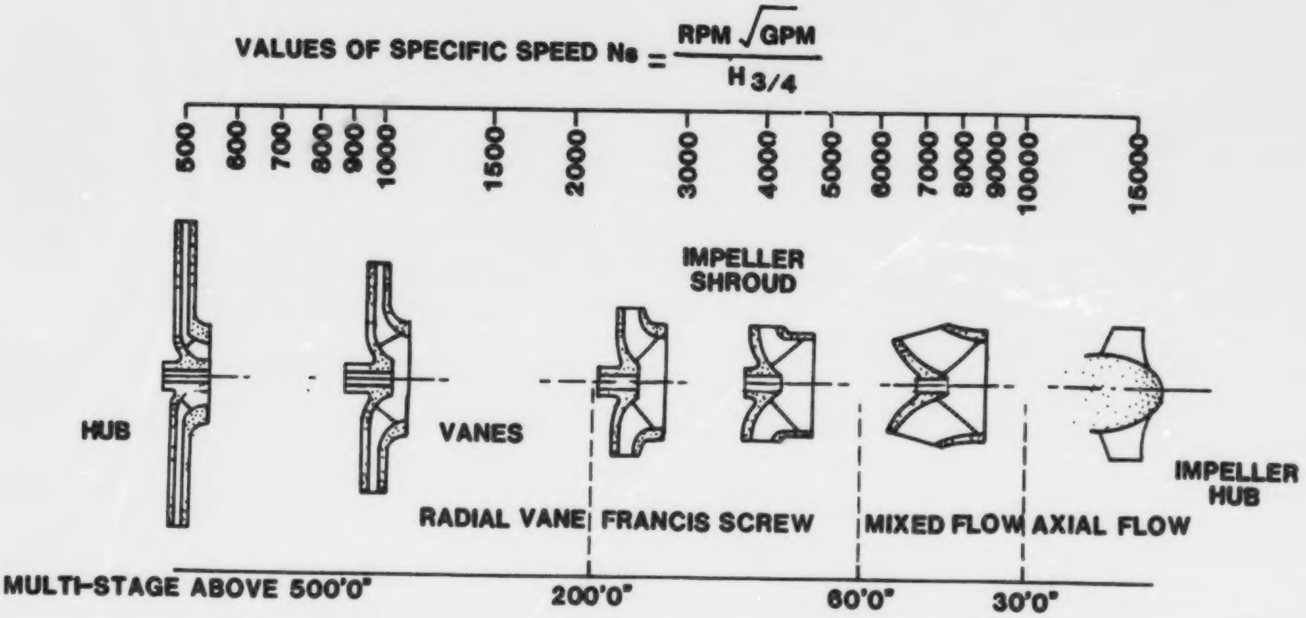

VALUES OF SPECIFIC SPEED Ns = RPM √GPM / H 3/4
500
600
700
800
900
1000
1500
2000
3000
4000
5000
6000
7000
8000
9000
10000
15000
IMPELLER SHROUD
HUB
VANES
IMPELLER HUB
RADIAL VANE
FRANCIS SCREW
MIXED FLOW
AXIAL FLOW
MULTI-STAGE ABOVE 500'0"
200'0"
60'0"
30'0"

FIG.4-91PUMPS AS TURBINES -IMPELLER SHAPE VERSUS SPECIFIC SPEED & HEAD

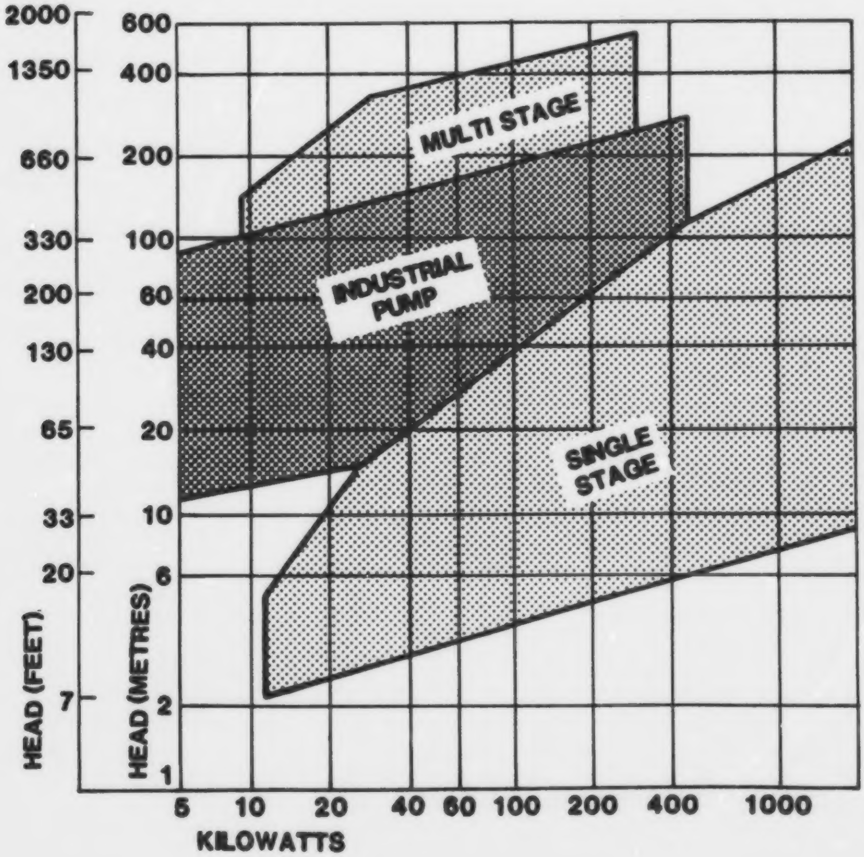


FIG 4-92 PUMPS AS TURBINES – APPLICATIONS RANGE

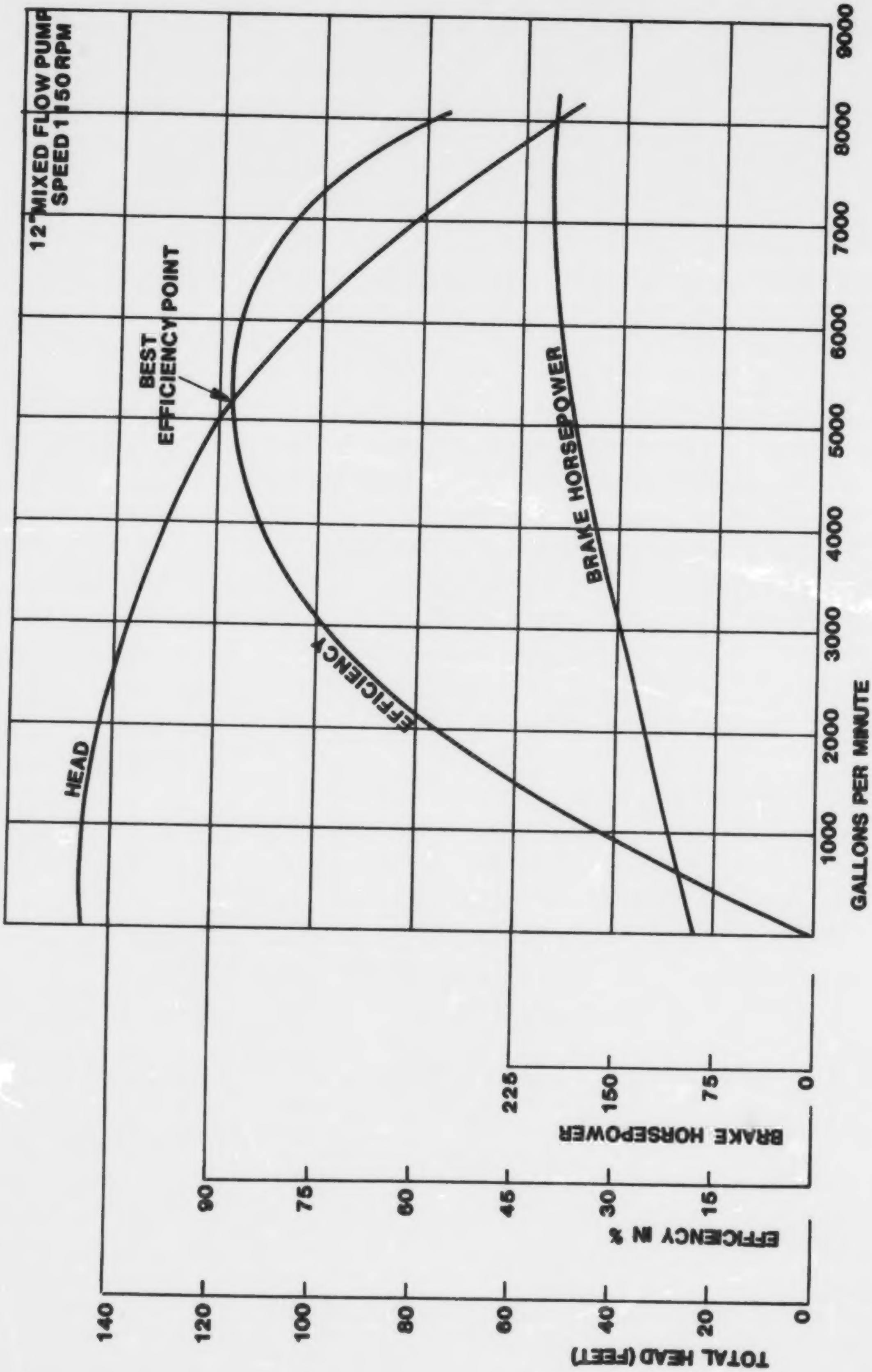

12" MIXED FLOW PUMP
SPEED 1150 RPM
BEST EFFICIENCY POINT
HEAD
EFFICIENCY
BRAKE HORSEPOWER
GALLONS PER MINUTE
1000
2000
3000
4000
5000
6000
7000
8000
9000
TOTAL HEAD (FEET)
0
20
40
60
80
100
120
140
EFFICIENCY IN %
15
30
45
60
75
90
BRAKE HORSEPOWER
0
75
150
225

FIG.4-93

The most common error in pump turbine selection is the selection of a pump from a catalog using pump design conditions. Catalogs describe pump duty, not turbine duty, so the result will be an oversized unit which will not operate properly. As a rough rule, the turbine will be about half the size of the pump needed for a given capacity.

If cavitation is to be avoided, pumps as turbines must operate with a certain minimum exhaust head obtained by means of a draft tube similar to that of a Francis turbine. The correct length of the draft tube is turbine specific, and must be obtained from the manufacturer or from a pump application engineer.

Wide angle suction pipes designed for pumps will not work in the turbine mode. A new draft tube must be made up in the form of a straight conical diffuser.

As an indication, the length of the draft tube, measured from the centreline of the pump discharge orifice to the bottom end of the draft tube on horizontal units, varies from about 18 feet in the case of high head (1200 feet) pump turbines to 1.5 feet for propeller turbines. However, draft tubes are likely to be relatively shorter on very small turbines. Draft tubes which are too long or too short for a given installation will cause cavitation, which shows up as excessive and erratic noise. When conditions are good, pumps as turbines are smooth running. Cavitation causes rapid and excessive wear to the impeller, and can often be cured by a new impeller or different draft tube.

Pumps as turbines cannot be effectively throttled below about 80 percent full load. The throttle valve for pumps as turbines should be a geared butterfly valve, since this type causes the least flow disturbance. This valve should be situated well upstream of the turbine, but when this is not possible, a flow straightener should be installed between the valve and turbine. Flow can also be controlled by means of headgates, inlet valves, or a bypass line. The throttle valve is fine-tuned with the electronic load controller so that the turbine output can be matched to the generator full load torque: the valve is then locked in position. For normal or overspeed shutdown use, install an additional gate valve.

For drives above 150 kW, it is usually necessary to install a speed increasing gearbox. These are quite expensive, and the selection should be left to an experienced manufacturer. For high head sites, it may be possible to obtain a sufficiently high speed to enable direct coupling to the generator.

With electronic load control, flywheels should not be necessary unless there is a substantial motor starting duty.

Typical "Name Brand" Pumps

Ingersoll Rand
Worthington
Byron Jackson
De Laval
Hayward Tyler
Goulds
Fairbanks Morse
Berkeley
Bingham-Willamette
Peerless
Flygt
Cornel
Hamworthy
Johnston
Paco
Paramount
Pumps & Power
Gorman Rupp
W.H. Allen

4.22 GENERATORS

Principle of Operation

The principle of operation of generators and motors is quite simple: when a wire is moved past a magnet so as to cut through the magnetic field, a voltage is induced in the wire. Three components are necessary: motion, magnetism, and a wire.

In generators, alternators and motors, either the wires are moved through the magnetic field, or the magnetic field is moved through the conductors. The effect is the same.

A.C. generators (sometimes referred to as alternators) produce a varying voltage which alternates above and below to zero voltage points. In effect, the current oscillates back and forth in the electrical circuit in response to the driving voltage. Three phase currents consist of three overlapping single phase voltages displaced 120° from each other.

Speed

All generators must be driven at constant speed to produce a constant 60 Hz frequency. R.P.M. is determined by the number of poles in the generator.

$$\text{Poles} = \frac{\text{RPM} \times \text{number of poles}}{2 \times 60}$$

$$\text{RPM} = \frac{2 \times 60 \times \text{frequency}}{\text{poles}}$$

where rpm = synchronous speed
frequency is assumed to be 60 Hz

Standard rpm for small A.C. generators, 60 Hz:

Poles	Standard RPM
2	3600
4	1800
6	1200
8	900
10	720
12	600

The 2-pole speed of 3600 rpm is too high for practical small hydro use. 1800 rpm is most commonly used, with 1200 rpm second. The cost of generators is more or less inversely proportional to speed: the lower the speed, the larger the frame size must be for equivalent output. For this reason, speeds below 1200 rpm become costly, but occasionally circumstances will justify their use. Where low speed low head turbines are involved, gear boxes are often used to raise the speed. There is a trade-off between the speed ratio, cost of the gear box, and cost of the generator. See Mechanical Power Transmission for comments on gear boxes.

Construction

Modern generators are normally supplied as a packaged unit, meaning the voltage regulator, voltage adjusting rheostat, field circuit breaker, and instrumentation for volts, hertz and amperes are installed in a box on the back end of the generator. It is possible to purchase a bare generator with separate voltage regulator and instruments for mounting in a separate switchboard. This is often done on sizes over about 100 kW. Voltage regulators are obtainable as separate modular units to fit a wide range of generator ratings and types. Various frame styles or enclosures are available, the most common one being "open protected". For some applications, drip proof or total enclosed frames are used.

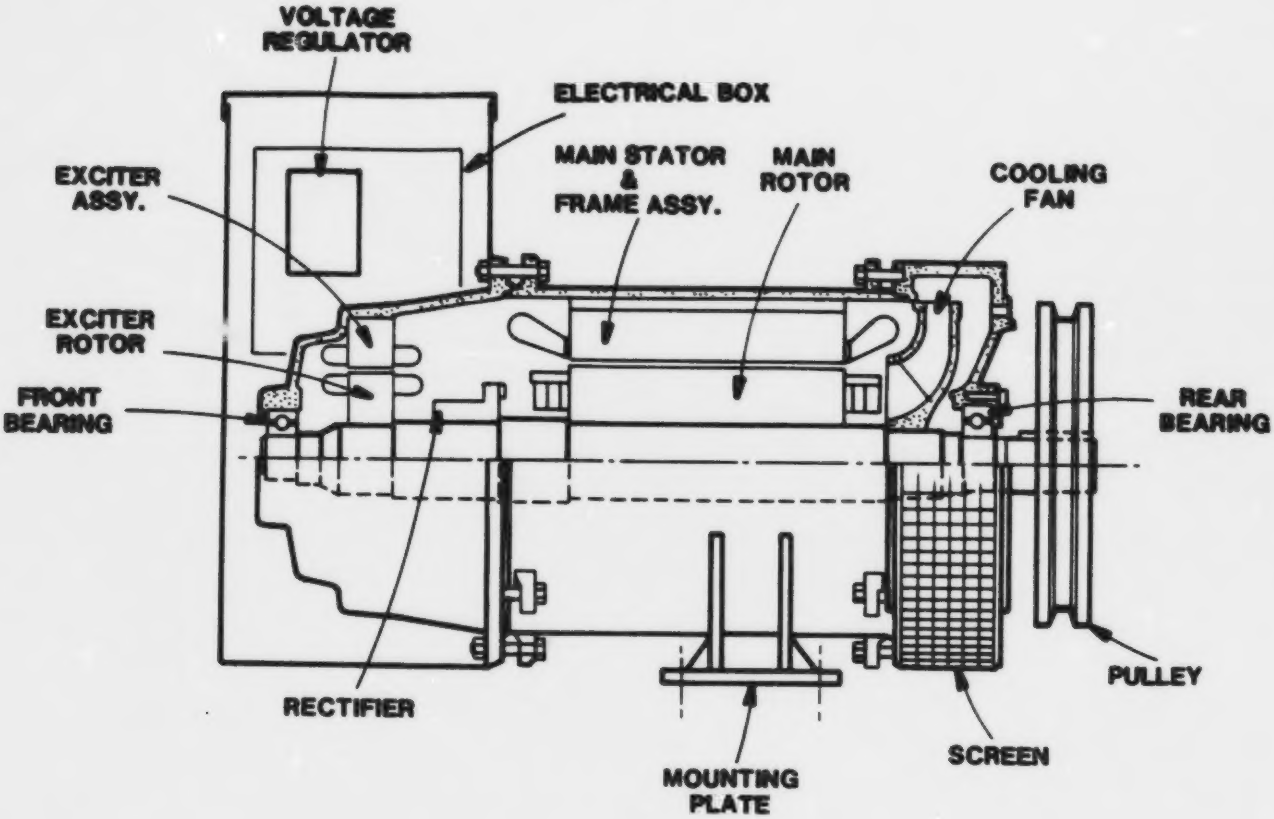

VOLTAGE REGULATOR
ELECTRICAL BOX
EXCITER ASSY.
MAIN STATOR & FRAME ASSY.
MAIN ROTOR
COOLING FAN
EXCITER ROTOR
FRONT BEARING
REAR BEARING
RECTIFIER
PULLEY
SCREEN
MOUNTING PLATE

FIG.4-94DOUBLE BEARING GENERATOR

Standard Voltages:

The standard system voltages at the point of use are 115/230V single phase, and either 120/208V, 440V, or 575V three phase.

Generator voltages are available in a wide range of optional voltages to meet the needs of the diverse market into which generators are sold. When purchasing a generator you must specify the required voltage, which is higher than the standard system voltages.

Generator rated voltage to match the above system voltages are:

System	Generator Voltage
115/230 volts single phase	120/240 V
120/208 volts three phase	127/220V Y
440 volts three phase	277/480 Y (becoming obsolete)
575 volts three phase	348/600 Y
575 volts three phase	600 V delta

600 volt generators are sometimes supplied 600 volt delta (see "Three phase systems"), which does not ordinarily affect connections or use.

Regulation

The generator voltage tends to drop in proportion to the load on the machine because of losses in the generator. This effect is offset in modern generators by the voltage regulator. Most builders limit voltage drop or "regulation" to within plus or minus two percent from no load to full load at 0.8 power factor, (see "Power Factor"), although one percent is available. A voltage adjustment dial, provided on most voltage regulators, will adjust the generator output voltage an additional plus or minus five percent. This control is usually built into the generator control box, but can be installed on the main switchboard.

Standard Generator Ratings

Industry standards list standard ratings. In practice, however, available ratings will vary considerably from one manufacturer to another. Generators are customarily rated in kilowatts at 0.8 lagging power factor. 0.8 power factor is an assumed industry standard. Kilowatts at 0.8 power factor equates, for the purpose of standardization, with rated kVa (for discussion on kW and kVa, see "Power Factor").

Example:

$$45 \text{ kilowatts at } 0.8 \text{ p.f.} = \frac{45}{0.8} = 56.25 \text{ kVa rated}$$

Overspeed

Industrial grade generators are rated for 25 percent overspeed, but can be 50 percent. Since turbine runaway speeds are typically 1.8 to 2 times operating speed, generators intended for use in small hydro systems require special overspeed capabilities. If or when overspeed occurs, industrial generators or others not specifically speed rated are at risk, and may or may not withstand the mechanical forces involved. The system overspeed requirements must be spelled out in the specifications, however not every manufacturer will offer generators rated for runaway speed. There is less problem with runaway speed on 1200 RPM generators, and certain makes of standard generators will withstand 1.8 times normal speed for short periods.

Efficiency

The efficiency of generators varies somewhat with the size of generator, load, and power factor. There is little difference between manufacturers.

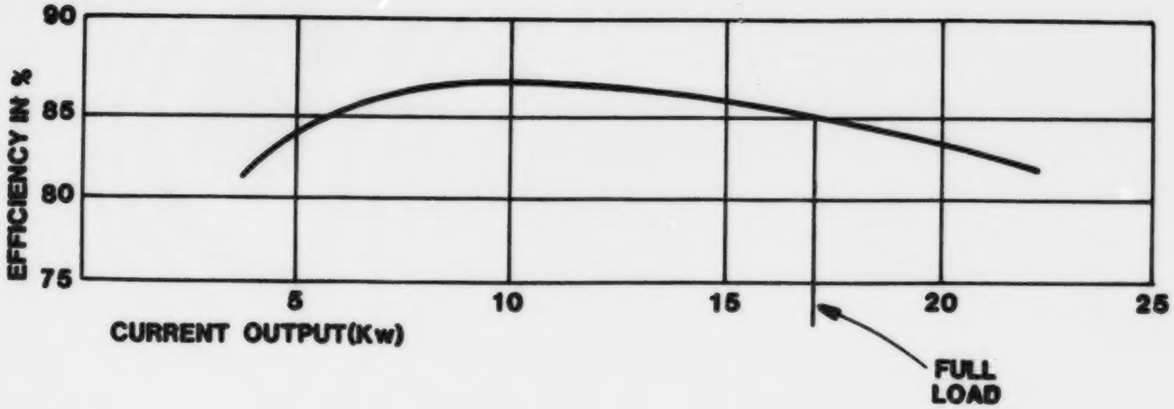


FIG.4-95EFFICIENCY CURVE:17Kw GENERATOR

Rating and Service Factor

Modern small generators have a service factor of one. That is, they will deliver continuous rated full load without exceeding the maximum internal temperature. They will also deliver a 10 percent overload for 2 hours out of a 24 hour period. A cooling air inlet temperature of 40°C is assumed. Older generators and larger utility machines are customarily rated for a service factor of 1.15, equal to a continuous overload of 15 percent. Modern generators will carry short term overloads greater than 10 percent, but not necessarily on top of a full load condition. Typical short term overload rating is 50 percent for one minute. Where short term overloads are anticipated, the manufacturers should be consulted.

Class F insulation is usually specified. Rating can be specified at either 80°C or 105°C over 40°C ambient, or for standby use, 130°C. Higher temperatures affect winding life, so that rating should be specified for 80°C.

Kw	208V	220V	240V	380V	400V	440V	450V	480V	600V	2400V	3300V	4160V
5	17.5	16.5	15.2	9.6	9.1	8.3	8.1	7.6	6.1			
7.5	26.1	24.7	22.6	14.3	13.6	12.3	12	11.3	9.1			
10	34.7	33	30.1	19.2	18.2	16.6	16.2	15.1	12			
15	52	49.5	45	28.8	27.3	24.9	24.4	22.5	18			
20	69.5	66	60.2	38.4	36.4	33.2	32.4	30.1	24	6	4.4	3.5
25	87	82.5	75.5	48	45.5	41.5	40.5	37.8	30	7.5	5.5	4.4
30	104	99	90.3	57.6	54.6	49.8	48.7	45.2	36	9.1	6.6	5.2
40	139	132	120	77	73	66.5	65	60	48	12.1	8.8	7
50	173	165	152	96	91	83	81	76	61	15.1	10.9	8.7
60	208	198	181	115	109	99.6	97.5	91	72	18.1	13.1	10.5
75	261	247	226	143	136	123	120	113	90	22.6	16.4	13
80	278	264	240	154	146	133	130	120	96	24.1	17.6	13.9
100	347	330	301	192	182	166	162	150	120	30	21.8	17.5
125	433	413	375	240	228	208	204	188	150	38	27.3	22
150	520	495	450	288	273	249	244	225	180	45	33	26
175	608	577	527	335	318	289	283	264	211	53	38	31
200	694	660	601	384	364	332	324	301	241	60	44	35
250	866	825	751	480	455	415	405	376	300	75	55	43

FIG.4-96KILOWATT/KVA/AMPERE CHART

Safety

Safety of any electrical installation is only as good as the care taken in the design and installation. The main safety requirements from an electrical point of view are prevention of electrical shock and fire hazard. The installation and wiring of the generator and associated equipment should be done by qualified personnel, and must be done in accordance with thr requirements of the Canadian Electrical Code. Particular attention must be given to grounding, and ensuring that the generator is adequately protected against short circuit and overload conditions. Humidity tends to be high in small hydro plants, and for this reason control panels should have internal heaters.

Reliability

Maximum reliability will be achieved when the following conditions are met:

(a) the mechanical and electrical design is suitable for the purpose intended;

(b) routine maintenance is faithfully and adequately performed, using specified lubricants, and spare parts;

(c) the plant is never abused through careless operations which result in overloading, short circuit, bad synchronizing attempts, or physical damage caused by rough handling;

(d) a plan for yearly maintenance and testing is instituted and carefully followed;

(e) sufficient spare parts are stocked so that replacements can be quickly made and downtime held to a minimum;

(f) brochures, instruction sheets and operating manuals are read and understood (all such material should be safely filed in the power plant);

(g) maintenance and repair operations are planned, thought-out, and understood prior to necessity.

Power Factor

Generators should be rated in kW and power factor, for example 40 kW @ 0.8 p.f. See Power Factor section for further discussion. An important concern to remember is that the turbine controls frequency and delivers kilowatts only. The generator controls voltage, and supplies kilowatts and reactive power. KVA ratings assume a .8 power factor.

Generator and System Protection

The class and extent of generator protection depends to some extent on the rating of the generator. For instance, protection for a 15 kW generator is less complex than protection for a 250 kW unit.

Generator protection is designed to protect the generator against faults originating outside the generator; these include short-circuit and overload protection. On small plants, arbitrarily below 75 kW, adequate generator short circuit and overload protection cannot always be achieved by means of thermal magnetic circuit breakers which in smaller sizes are non-adjustable. Thus, most small generators run unprotected. Protection can be assured by adding adjustable overload relays which will trip the circuit breaker by means of a shunt trip coil. On larger plants, short circuit and overload protective systems are achieved by other means.

Over and Under Voltage Protection

Over and under voltage protection relays will trip the circuit breaker when voltage is above or below a set figure. There is a time delay function which allows for motor starting at switching of large block loads. Sustained over or under voltage may be caused by voltage regulator or governor failure.

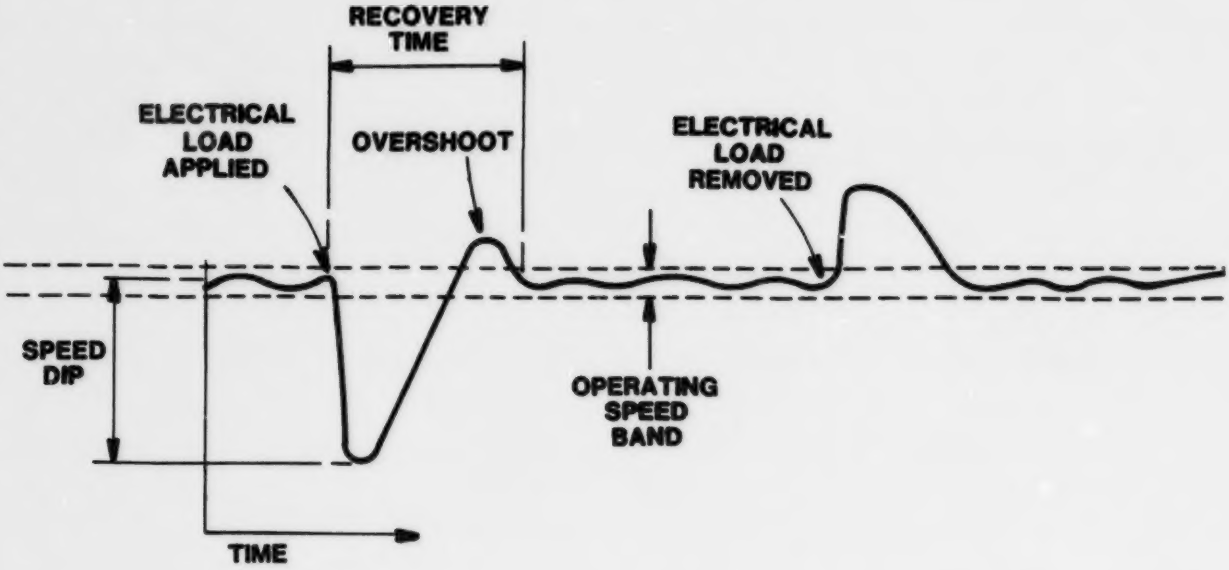


FIG.4-97VOLTAGE VARIATIONS CAUSED BY SWITCHING LOADS

Over and Under Frequency Protection

Over and under frequency protection relays will trip the circuit breaker when frequency is significantly above or below 60 Hertz. Again, the time delay function prevents nuisance tripping on temporary frequency excursions. Frequency will vary for the same general causes of voltage excursions, and to some extent, the voltage and frequencies act as back-up for each other.

Field Breaker

Generators supplied with integral control panels are usually supplied with a field winding circuit breaker, which protects the field winding from high voltages and currents. The breaker also acts to limit damage in the event of a field winding fault. Certain manufacturers use this breaker to trip the field circuit when the application of excess field current exceeds five seconds. Excess field current occurs when constant voltage regulators attempt to maintain full voltage on the application of heavy loads. Field protection is available as an option, and should be specified on larger generators.

Extended Protection

Machines above an arbitrary rating of 75 kW should incorporate an important additional feature: the overcurrent protection should be derived from current transformers and overload relays, rather than relying on the circuit breaker protective elements. Such protection should include instantaneous and very inverse time overload protection. A partial list follows:

winding temperature indicators
reverse power
ground fault protection
additional overcurrent protection
additional short-circuit protection

Paralleling

When two generators are necessary to carry the load, they must be connected together or "paralleled". See "Synchronizing" for details. Modern generators will usually parallel without difficulty, but a paralleling kit usually must be obtained from the generator manufacturer.

Professional Assistance

Generator and turbine manufacturers will provide advice when given details of the system. However they usually do not have either the time nor the specialist staff to make many of the decisions necessary to arrive at a complete and satisfactory overall system. The generator, after all, is only a part of the total system and many factors must be taken into account when rating and specifying a generator. Factors such as paralleling, short circuit coordination, permissible voltage dip, voltage type, and regulator require much much thought and planning.

Generators above 100 kW should be specified by consultants or engineers. Sample specifications are provided in Specification and Costing, Chapter 6.

4.23 MECHANICAL POWER TRANSMISSION

Mechanical power transmission parts include couplings, sheaves, belts and gears. The satisfactory operation of rotating machinery depends in large measure on the correct application and installation of power transmission parts. Components such as sheaves, belts and couplings are made to industry standards and are in inch sizes. For this reason, this section is in Imperial measures. Metric equipment as yet is obtainable only to special order. This is an important consideration, as power transmission components must be specially machined to fit generators built to metric standards.

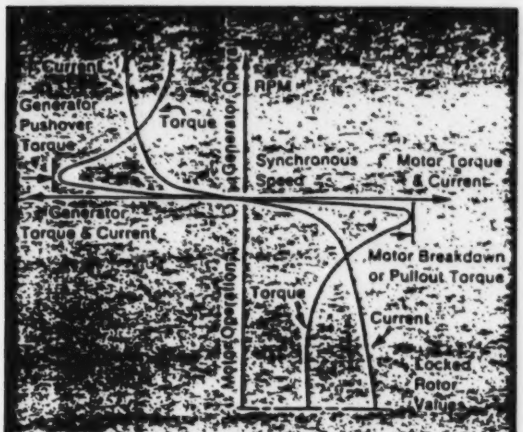


TABLE 1 Speed torque characteristics of motor and generator. Change in equivalent circuit constants results in generator pushover torque being higher than motor breakdown torque.

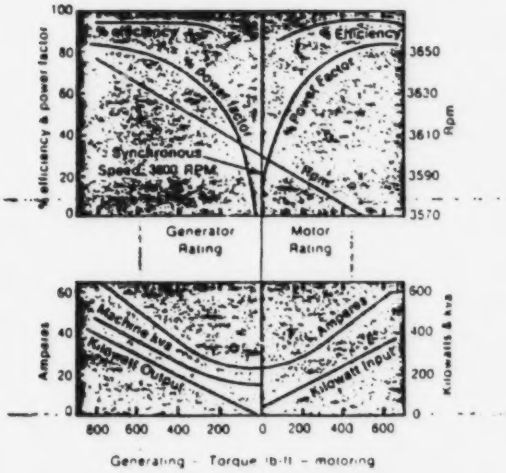


TABLE 2 Typical performance curves for a small 2-pole induction generator

FIG 4-98
INDUCTION GENERATOR
CHARACTERISTICS

Gear Drives

Speed increasing gears are commonly used in conjunction with larger, low head turbines. Gearboxes are used to match low speed turbines with high speed generators; and therfore contribute to an overall cheaper installation, because high speed generators are much cheaper than low speed ones.

Gearboxes are sometimes built by the turbine supplier, but a wide variety of types, ratios, and sizes are obtainable from industrial sources. Occasionally, right angle gearboxes are used to connect a vertical turbine to a horizontal generator. Marine reduction gearboxes are often used as they are readily available in large sizes.

Gear drives may be useful in small low head sites where a speed ratio of more than three or four to one is required. At these higher ratios, belt drives become questionable. Gear ratios of up to 5.5:1 are obtainable using a single pair of spur, helical, or herringbone gears. Ratios higher than 5.5:1 require double reduction with four gears or a planetary arrangement.

Gear drives require careful installation and alignment, use special lubricants, and in large sizes often need oil coolers and lube oil pumps. They are rated in maximum torque, and maximum rpm. There are restrictions on shock loads and running temperature. Efficiency is quite high for low ratio gear boxes, typically 95 percent. Couplings and other details depend upon relative torque.

Shaft Alignment

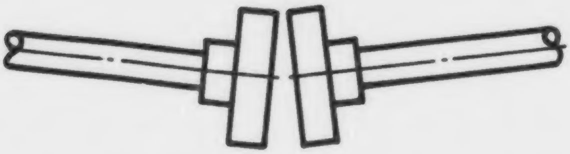
Shaft alignment is critical for long lasting reliable operation. For standard flexible couplings, either lubricated or non-lubricated, the maximum permissible angular error is one degree: expensive couplings will handle more, possibly up to one and a half degrees. Given time and patience, getting within half of one degree or better is not too difficult.

Aligning machines on a steel sub-base is far easier than attempting to align on a concrete floor. Direct coupled machines should always be supplied with a steel sub-base or the assembly can be made by the turbine-generator builder.

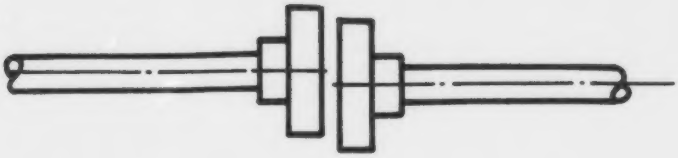
Belt driven units are easier to install on a concrete floor when a slide rail generator base is used.

Alignment kits which contain instructions for use can be rented from power transmission equipment firms.

FIG.4-99ALIGNMENT



ANGULAR MISALIGNMENT



PARALLEL MISALIGNMENT

Maintenance

Maintenance of mechanical power transmission components consists of:

(a) periodically inspecting for loose bolts and signs of looseness or wear on sheaves, belts, couplings and bearings;

(b) replacing lubrication: obtain a lube schedule from the equipment manufacturer and use only recommended lubricants;

(c) maintaining a log of all inspections, repairs and replacements;

(d) rechecking bolts, belts and couplings after a short circuit or bad synchronizing;

(e) keeping a stock of lubricants, spare belts and a spare elastomeric element for the couplings;

(f) possibly stocking a set of new bearings for the turbine and generator. If you decide to do this, learn how to replace the bearings in your equipment. You may need special tools such as bearing pullers, and lifting equipment;

(g) stocking some spare parts for electronic governors, control circuit equipment, contactor coils, and spare contacts. Although stocking turbine spare parts is more a convenience than a necessity. Your equipment supplier will advise on this.

Changing bearings in machines larger than 15 kW should be done by an electric motor mechanic, mainly because generator rotors are surprisingly heavy, and removal and replacement into the stator bore is very tricky. It is easy to inadvertently damage the windings. Reference to bearing maintenance and replacement is given at the end of Chapter 4.

If no relubricating schedule is available, ball bearings should be greased two to three times per year. To do this, remove the drain plug from the bottom of the bearing and then pump in sufficient grease to refill the bearing. Run the machine for 20 minutes, replace the drain plug, and wipe off excess grease. Bearing suppliers can estimate the correct volume of grease to suit the size of your bearings.

Bearings equipped with Alemite or Zerk grease fittings, should not be greased too often, unless conditions are very dirty or the bearings are exposed to water. The excess grease can be forced into the interior of the generator where it gets into the windings. If this is allowed to happen, the grease attracts dust and builds up a layer of thermal insulation which raises the winding temperature.

Safety

If rotating parts are well guarded and maintenance is faithfully performed, the equipment should be safe, from a mechanical point of view. Keep the equipment and the floor clear of loose tools, parts, oil and water. Safety requirements for electrical components are covered in the Electricity Transmission section to follow.

Vibration

All rotating machines vibrate, and good design practice ensures that vibration is held to a practical minimum. Vibration is either linear, which is caused by unbalanced forces usually in more than one plane; or torsional, which is caused by forces making the shaft twist and untwist like a rotating pendulum. Linear balancing, provided on generators, couplings and sheaves, is done on balancing machines which allow for various conditions; this is called static and dynamic balancing. Turbines should be statically and dynamically balanced, and this requirement should be stated in the contract.

Torsional vibration in hydro units can be caused by vibratory forces generated in impulse turbines; and by hydraulic forces and cavitation in other types of turbines. The likelihood of torsional vibration can be calculated when all of the design details of a particular installation are known. The turbine builder should run a check on each machine.

Vibration Detectors

On remote, unattended sites, vibration detectors are often specified on larger equipment. Vibration detectors can be supplied to respond to specific conditions such as displacement, rate of vibration, velocity and acceleration. The problem is to decide which of the many vibrations should be detected, and what amplitude is a sign of impending failure. Displacement measurements are better indicators of dynamic stress and more commonly used. The turbine builder will usually recommend the best type and location for vibration monitoring devices; otherwise specialist firms can advise. Displacement should not exceed two to three mils.

Shock Impulse Detectors

Ball and roller bearing life can be monitored by means of a shock impulse detector which measures the minute, but gradually increasing impacts of the rollers against the cage. When the impacts reach a certain level, the bearings are changed. This avoids failures during operation, which can cause extensive damage.

Noise

All machinery has a characteristic sound, of which vibration is a normal component. You will quickly get used to the sound of your hydro plant, and will be able to detect unusual noises or excessive vibration.

Sound and vibration characteristics of new machinery can be compared with recordings taken as the machinery ages. This is a very useful maintenance check on larger equipment, and will often forecast impending mechanical troubles such as worn bearings and loose components.

Professional Assistance

Professional design of turbine-generator bases, mounting arrangements, and power transmission components on sizes above 100 kW is recommended.

Flywheels

Flywheels are sometimes supplied for hydro plants. The purpose is to slow down the rate of acceleration of the hydro unit on sudden load rejection. This gives the governor more time to act, and limits the speed rise. Flywheels also steady the running of the set on varying demand such as intermittent motor loads. Flywheels must be precision made, with particularly accurate static and dynamic balance.

Installation on the shaft must be very accurately done, preferably by bolting the flywheel to a shrink or press fitted hub or by using ringfitters. Guards are necessary. Up to a certain size, flywheels can be installed on either the turbine or generator shaft. Beyond that, use a three-bearing turbine design, which has an additional bearing between the flywheel and the generator. In all flywheel installations, the weight should not be divided between the generator and turbine bearings, nor for that matter should a heavy flywheel be supported wholly on the generator. In the latter case, special generator bearings are necessary, and add greatly to the cost.

4.24 INDUCTION GENERATORS

An induction generator consists of an ordinary three phase motor driven a little above its synchronous speed. When the motor is connected to the utility, it will draw excitation (reactive power) from the line to establish its magnetic field, and so energized, will feed kilowatts into the utility. The energy delivered depends on how much above its synchronous speed the motor is driven. Motors on load have "slip"; that is, they run at a speed below their synchronous speed. For example, most 1800 rpm motors actually run at 1750 rpm on load, or about 50 rpm low. To generate, they must be driven at negative slip speed, or about 50 rpm high, say 1850 rpm.

Induction generators do not need to be synchronized. When the turbine generator is started, the speed is brought up to "null speed", (i.e. exact synchronous rpm) and closed in on the line. By so doing, no current surges are produced. The speed is then brought to full load speed. The grid will lock the frequency on 60 cycles, so that turbine governing is not necessary. If water runs short, the speed will drop until the induction generator begins to run as a motor at a speed less than synchronous rpm. Relays are normally provided to prevent motoring. Since the induction generator derives its excitation from the power line it is connected to, it cannot be used as a stand-alone plant.

Induction generators show important advantages as a means of supplying energy into a utility grid, and in practice this is the sole application. Many utilities have one or more induction generators on their system. Historically, these have been larger sizes up to 5000 kW, but in recent times many small independent units have been installed, notably in the north eastern and north western United States. It is quite possible to tie a small induction generator into an isolated synchronous system, but this should not exceed 20 percent or 25 percent of the synchronous generator capacity. Power factor correction on the synchronous generator may be necessary.

Protection and Control

Induction generators do not require synchronizing gear, nor voltage regulators, but are sometimes supplied with a simple droop governor which controls the inlet valves or gates. Output conditions for both voltage and kilowatts are achieved at a speed which is a small increment above the normal synchronous speed of the machine. The induction generator can feed power into a dead utility line where the capacitance of the line is sufficient to cause excitation. If the induction generator delivers a small fraction of its load into a local supply system, synchronous motors or capacitors can cause excitation. Under such circumstances, the induction generator can supply up to 30 percent of rated voltage into a 'dead' line, and therefore to prevent this, protection and control features similar to the techniques used on synchronous generators must be designed.

Type of Equipment

Ordinary A.C. motors can be used as induction generators, and are much more robust than equivalent synchronous generators. They can be purchased for a fraction of the cost, and will usually withstand twice rated speed without difficulty. A few generator manufacturers produce induction generators which have small improvements in characteristics over ordinary A.C. motors.

On induction generators the control panels will be simpler and less expensive. Protection usually includes short circuit and overload, reverse power, overspeed, underspeed, and such other features as may be required by the local utility. Overspeed protection will be similar to that required for synchronous plants, since the machine should not be allowed to run at high speed for any length of time. The turbine can be of any suitable type, but induction generators are very often driven by pump turbines since governing is not required. Flywheels are not necessary because of the stiff utility connection.

Professional Assistance

Turbine builders and suppliers of generators and motors can supply examples of installations. The electrical aspects of such installations should be professionally designed.

4.25 SYNCHRONIZING

When a diesel plant is necessary to augment the energy supply, and must run in parallel with the hydro plant, synchronizing is necessary. Small communities may have facilities such as dispensaries or schools which may be seriously inconvenienced by short breaks in the power supply. Many small isolated hydro systems require diesel standby power, and will often retain the original diesel plant for this purpose. On other hydro systems, where the hydro plant customarily runs short of water at certain times, the diesel plant may be required to furnish all or a part of the load for considerable periods of time. In cases where the diesel acts as a standby supply, synchronizing can be avoided by shutting down one generator prior to connecting the other. The load can be re-directed by means of a transfer switch.

All A.C. systems must be synchronized prior to being connected together. The speed, voltage, and angular relationship between the voltage waves of the two generators must be equal. If these conditions are not correct at the moment of connection, heavy currents and severe mechanical shock will result. The running machine tries to jerk the incoming one into synchronism, and in severe cases, expensive noises will result. Worst case scenarios include sheared couplings, broken crankshafts and wrecked generators. Synchronizing by hand is a matter of judgement and experience. The possibility of damage is known to the operator, so that the necessity of synchronizing often becomes an occasion for apprehension.

In recent years, semi-automatic or fully automatic synchronizing equipment has become reasonably priced, and therefore should be installed. Automatic synchronizing will pay for itself in reduced maintenance. By reducing the need for judgemental skill, automatic synchronizing becomes a routine event, and can be done safely by inexperienced operators.

Auto Synchronizing

Auto synchronizing utilizes a relay which measures the difference in speed (slip frequency) and the phase angle between the generator voltages. The relay is adjustable for slip frequency, circuit breaker closing time, and the frequency-matching impulse lengths which it applies to the governor speed. When conditions are correct, the relay will, depending on type, either:

(a) indicate by means of a ready-to-close lamp that conditions are correct. The operator then closes the circuit breaker. This is called permissive paralleling; or

(b) send a 'close signal' to the circuit breaker. This is called semi-automatic synchronizing.

Parallel Operation

Parallel operation of small hydro generators with other hydro units or with diesels is usually trouble free, provided these basic criteria are observed:

(a) their voltages must be the same;
(b) their frequencies must be the same; and
(c) their phase sequence must be the same.

The first two conditions must be met at the time that the generators are specified, and also the output controls of the generators must be adjusted when put into operation. The phase sequence requirement can be satisfied by observing the manufacturer's instructions regarding phase sequence during installation. This is simple to check by connecting a small A.C. motor to each generator in turn. The motor should run in the same direction in both cases. If not, swap any two generator leads on the generator being installed.

Response to load changes will be affected by relative sizes of the equipment, inertia, and governor characteristics. Usually, some minor complications arise in selecting the relative governor settings, and experienced advice may be necessary. When purchasing an additional generator, or adding either a diesel or a hydro generator to an existing system, the vendor should be provided with details of the system. It is possible to arrange for fully automated start-up, synchronization, and shut-down of either the diesel, the hydro, or both in response to load or available water flows.

Load Sharing

Load sharing between the generators can be done by small adjustments to either speed or voltage. The higher speed or higher voltage machine will take most of the load.

Load sharing equipment which will divide the load between any two units is available. This may be useful if you want to maximize generation by the hydro unit when it is running in parallel with a diesel. Different droop settings will be necessary for both machines.

Paralleling Requirements

The generators should have damper windings, for which a paralleling kit is necessary. See section on generators for details.

Permissive Parallelling

The incoming generator is started and brought up to operating voltage and frequency as determined by the panel meters. The operator then places the synchronizing switch in the 'on' position. This energizes the synchronizing relay, and when conditions are correct, the relay illuminates the "ready to close" lamp. The operator then closes the paralleling circuit breaker. In the event that there are no other generators connected to the bus bar, the synchronizing check relay is bypassed by the action of an internal relay, and you can close without having to go through the paralleling routine.

Semi-automatic Paralleling

Semi-automatic paralleling works as above, but the operator places the circuit breaker in the 'close' position after switching on the synchronizing relay. When conditions are correct, the synchronizing check relay will send a closing signal to the paralleling circuit breaker. This scheme requires the use of a motor operated, molded case circuit breaker, or battery operated circuit breaker. Of the two systems, semi-automatic is preferable as it removes any chance of making a poor synchronizing connection, which permissive paralleling does not entirely prevent.

All synchronizing systems, either manual or relay based, may be fitted with a reverse power relay on each machine. This relay will prevent either generator from motoring upon failure of either the diesel or hydro turbine. Either permissive or semi-automatic paralleling should be specified when ordering the generator panel.

Installing synchro check relays on existing switchboards is usually possible, but this may necessitate changing the main circuit breakers and installing additional control devices and wiring. A site visit by the vendor's technician is almost always necessary.

4.26 POWER FACTOR

Power factor has to be considered when dealing with A.C. circuits and equipment, especially those containing iron core equipment such as motors and transformers. This type of equipment requires an extra current to magnetize the iron cores. Therefore, in addition to the current which converts to work done, there is an extra circulating current in A.C. circuits which is necessary to magnetize the cores, but does no useful work. You must allow for this current when sizing generators, transformers, and cables. This extra current is called reactive current or reactive power.

Power factor can be expressed as the ratio of active power (kilowatts) to apparent power (kilowatts plus reactive power), and is customarily expressed as a decimal fraction such as 0.8. Power factor varies from 1, which is unity power factor, and equal to kilowatts, to lower values such as 0.55 lagging for unloaded electric motors. Power factor can be either leading or lagging. Leading power factor is a characteristic of capacitors, which are used to improve or eliminate lagging power factor.

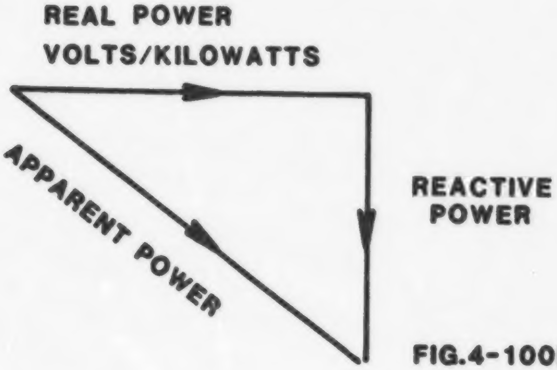


FIG.4-100POWER FACTOR DIAGRAM

The diagram is a vectoral representation of power factor. The cosine of the angle 0 between the line voltage and apparent power is the power factor.

Reactive power, kVaR, is always at 90° to kilowatts, and the resultant of the two is kVa or apparent power. The current is said to lag behind the voltage by this angle.

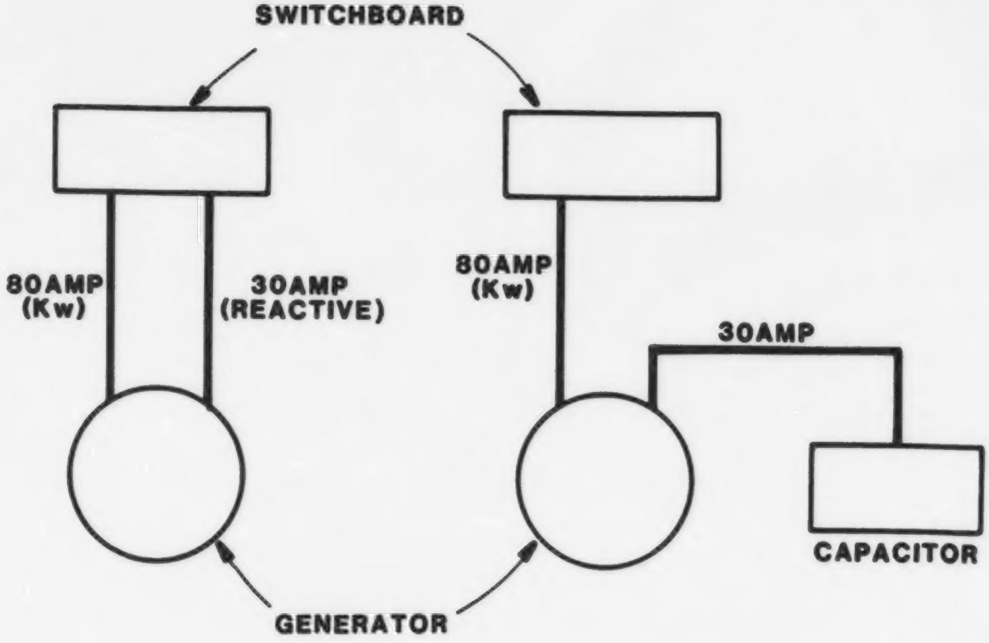


FIG.4-101POWER FACTOR CORRECTION

In the above diagram, the motor on the left draws 80 amps which converts to work done, plus 30 amp reactive current to magnetize the motor. The necessary reactive power is drawn from the supply system right back to the generator. In the case of the motor on the right, reactive power is supplied by the capacitor instead of the generator. Since power factor will be lagging to some extent in most A.C. systems, a power factor of 0.8 lagging is an assumed industry standard. This allowance is built into generators and transformers unless otherwise stated on the nameplate or by specification.

Most small systems supplying residences or small commercial premises will normally have a power factor of 0.9 or better. Systems which supply industrial loads, such as a sawmill or fabricating shop, may have power factors as low as 0.6, especially where motors are intermittently loaded or run under-loaded. The reactive power in low power factor systems results in poor utilization of generator capacity, cables and switchgear. Voltage regulation suffers, and over heating of generators and cables may result.

Power Factor in Relation to Equipment

Motors

The power factor of unloaded motors is typically 0.55 lagging, increasing to 0.8 to 0.85 lagging at full load. The reactive power does not change much from no load to full load, which makes motors an attractive application for capacitors. In practice, the usual place to correct power factors is at individual motors. The capacitor is installed at or near the motor and is switched on and off along with the motor.

Motor suppliers should always be consulted as to permissible capacitor value, since the correct size varies considerably between different makes and classes of motors. Motor power factor can be improved to between 0.95 and unity independent of motor load. Motor nameplates do not allow for power factor.

Figure 4-102 lists motor characteristics values for estimating purposes.

Figure 4-103 is a nomograph for power factor connection.

Generators

A.C. generators should be rated in kilowatts at 0.8 lagging power factor. That is, they are rated to deliver rated kilowatts, and at the same time deliver sufficient reactive power for an 0.8 power factor load.

Example 1:

Rating 45 kilowatts at 0.8 pf.
kVa = 45/0.8 = 56.25 kVa
Reactive power = 56.25 - 45 = 11.25 kVa.

Occasionally, generators may be rated in kilowatts at unity power factor. In this instance, the generator is not rated for reactive current and must be derated when feeding into a lagging power factor load.

Example 2:

Rating 45 kW at 1.0 (unity) power factor
Kilowatts at 0.8 p.f. = 45 x 0.8 = 36 kilowatts.

Cables

Cable rating, or ampacity, as given in the Canadian Electrical Code and many other codes and tables, does not allow for power factor. When establishing cable sizes, you must allow for the extra reactive current by assuming a power factor of 0.8 lagging unless it is more accurately known and cannot change.

Table 5. Typical three phase motor characteristics for NEMA Design B, C and D motors.

Typical 3 Phase Motor – Characteristics				
HP	RPM	Running KW	Running KVA	KVA Start
1	3600	1.05	1.3	13
	1800	1.06	1.4	12
	1200	1.02	1.5	12
2	3600	1.9	2.2	19
	1800	1.9	2.3	13
	1200	2.0	2.7	18
3	3600	2.9	3.2	25
	1800	2.8	3.4	24
	1200	2.8	3.7	24
5	3600	4.6	5.2	35
	1800	4.6	5.4	34
	1200	4.5	5.8	34
	900	4.5	6.3	33
7-1/2	3600	6.7	7.5	48
	1800	6.9	7.9	46
	1200	6.8	8.2	45
	900	7.0	9.3	44
10	3600	8.8	9.8	62
	1800	8.8	10.1	60
	1200	8.7	10.5	58
	900	9.4	12.3	56
15	3600	13.2	14.7	88
	1800	13.0	14.7	84
	1200	12.9	15.2	82
	900	13.7	17.4	81
20	3600	16.7	18.6	112
	1800	17.2	19.4	112
	1200	17.4	20.3	112
	900	17.4	21.6	110
25	3600	20.5	22.8	139
	1800	21.6	24.3	138
	1200	22.0	25.5	138
	900	22.0	26.2	136
30	3600	25.2	28	166
	1800	25.5	28.6	165
	1200	25.0	28.6	165
	900	25.5	31.1	161

NEMA Design B, C and D Motors ①				
HP	RPM	Running KW	Running KVA	KVA Start
40	3600	33.3	37	221
	1800	35.2	39	220
	1200	34.5	39.2	220
	900	34.6	41.3	216
50	3600	43.5	48	276
	1800	43.5	48	275
	1200	43.2	48	274
	900	42.0	49.9	272
60	3600	49.5	55	336
	1800	51.5	57	331
	1200	51.1	58	330
	900	51.3	61.2	328
75	3600	64	71	419
	1800	63	70	416
	1200	63	71.5	417
	900	66	77	414
100	3600	85	94	552
	1800	84	93	556
	1200	84.5	96	555
	900	86	99	552
125	3600	108	119	698
	1800	106	117	696
	1200	109	123	695
	900	113	127	690
150	3600	127	139	836
	1800	125	136	830
	1200	131	148	828
	900	136	153	820
200	3600	167	183	1110
	1800	164	180	1105
	1200	168	195	1100
	900	178	201	1060
250	3600	204	224	1380
	1800	200	220	1370
	1200	205	232	1360
	900	213	239	1345

① *Design A motor may have starting kVA values that are as much as 50% higher. Many 3600 rpm motors are designed A.*

FIG 4-102

kW—POWER FACTOR—kVA CHART

This chart can be used to examine the relationship between kW and kVA loading at various values of **power factor.**

Instructions

Place a rule to join the value of kW load and the value of power factor, thus intersecting the kVA scale, the point of intersection giving the corresponding value of kVA loading.

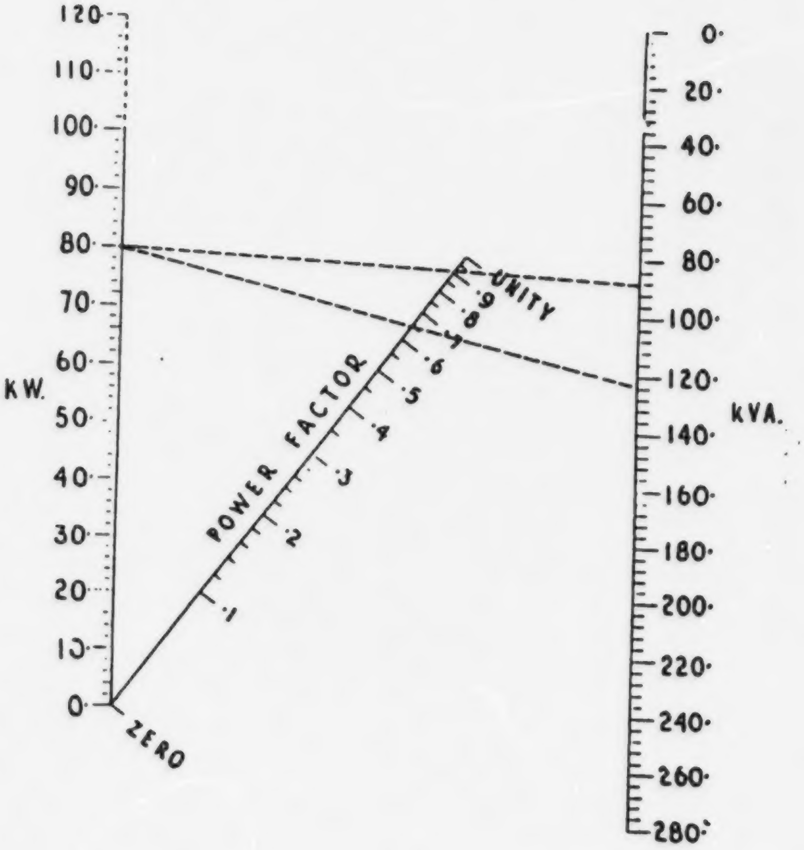
Example

To determine reduction in kVA loading by improving the power factor of a given kW load.

From chart:—	kW	Power Factor	kVA
	80	·65	123
	80	·90	89
			—
			34
			—

Therefore, the reduction in kVA loading is 34 kVA when the power factor of an 80 kW load is improved from ·65 to ·90.

For a given maximum kVA loading, the increase in kW loading that can be carried at various values of improved power factor can also readily be seen.



120·
110·
100·
90·
80·
70·
60·
50·
40·
30·
20·
10·
0·
K W.
ZERO
POWER FACTOR
·1
·2
·3
·4
·5
·6
·7
·8
·9
UNITY
0·
20·
40·
60·
80·
100·
120·
140·
160·
180·
200·
220·
240·
260·
280·
kVA.

FIG 4-103
POWER FACTOR NOMOGRAPH

Example:

Full load current (nameplate rating) = 60 amps.

To allow for 0.8 lagging power factor,
Cable rating $= \frac{60}{0.8} = 75$ amps.

Note: When sizing motor cables and main feeder cables, the minimum code cable size is 1.25 times motor current, which allows for power factor.

Lighting and Heating

Lighting and electric heaters contain little or no iron core components, and consequently the power factor of circuits feeding these devices will be at or near unity. On systems which are used mainly for lighting and heating with negligible motor load, power factor can be ignored. This applies to usual residential loads.

Transformers

Power factor is high on full load, and reactive power is small, one to two percent of full load current. It is not usual to correct it. Transformers are conventionally rated in kVa rather than kilowatts. The kVa rating is based on 0.8 lagging power factor.

Example

Transformer rating 45 kVa,
to 45 kilowatts at 0.8 p.f.
kilowatts at unit power factor $= \frac{45}{.8} = 56.25$ kW

A 45 kVa transformer will match ratings with a 45 kW 0.8 p.f. generator.

Rating of Capacitors

Capacitors must match your system in voltage and in kVaR, and must be provided with a fused switch.

Rules for installing capacitors:

(a) choose motors which have long hours of use;

(b) choose largest motors first;

(c) limit capacitors to values recommended by motor manufacturer;

(d) where the motor load consists of many dispersed small motor loads, located the capacitor at local distribution boards; and

(e) use to correct capacitance: too much is as bad as too little. Leading power factor has the same effect on cables and generators as lagging power factor.

Professional Assistance

When the electrical installation is professionally designed, your power factor corrections is, or should be, considered. Most industrial electricians and contractors can make on-site power factor measurement and can advise on the size and location of capacitors.

4.27 ELECTRICAL TRANSMISSION

General

Transmission of electrical energy at either low or high voltage is usually necessary. Only rarely will the hydro plant be located at the load centre, although every effort should be made to shorten the distance between the two. Transmission is always a major component of the total cost. There is a number of possibilities, and these will be described briefly. "Low voltage" is transmission at generator voltage which can be 120/240 volts, 460 volts, or 600 volts. "High voltage" transmission utilizes voltages of 2300 volts, 4160 volts, 7200 volts or higher.

Cable Capacity

Ampacity, or current rating of electrical cables, is given by the Canadian Electrical Code, C22.1, Tables 1 through 4. The ratings do not allow for power factor, so that when feeding motor circuits or distribution panels, cable ampacity must be multiplied by 1.25. This multiplier allows for motor starting current and power factor, not lower than 0.8 lagging.

Voltage Drop

Power factor, ohmic resistance, and reactance on A.C. circuits, cause a voltage drop to occur on all cables and transmission lines. Voltage drop calculations can be complex, so you can usually rely on voltage drop tables provided by electrical codes or cable manufacturers. Voltage drop tables and charts are sufficiently accurate to determine voltage drop for most problems. For most transmission systems longer than 150 feet, whether cables or overhead lines, voltage drop rather than ampacity will determine the cable size. Voltage drop on low voltage feeders should be limited to 2 percent to 2-1/2 percent. For reasons of economy, high voltage transmission lines are usually based on five percent regulation, and transformer taps are normally available to make the correction.

Power Loss

Power loss will occur in all transmission systems, and for small systems such as the ones under discussion here, the loss will be normally less than five percent.

Case 1 - Low Voltage Cables

Low voltage cables involve those in conduits, direct buried cables, or overhead triplex or quadruplex cables. Triplex and quadruplex cables consist of two or three insulated aluminium conductors spun into a bare messenger cable which is also the neutral. These cables are used extensively for residential service entrances, and for small commercial premises.

There are two main points to watch when selecting cables:

1. Ampacity of the cable must be adequate.
2. Voltage drop on main feeders must not exceed 2-1/2 percent.

As a rough guide, low voltage cable will be economic up to a few hundred feet; beyond that, high voltages must be used.

Low voltage, non-metallic, sheathed buried cable may be used on either 120/240 volt, or 120/208 volt, but 460 volt and 600 volt require an armored cable such as TECK 90.

Refer to Figure 4-104 thru 4-106.

High Voltage Transmission, Single and Three Phase

General Considerations

The transmission of energy over distances greater than 250 feet to 500 feet often requires the use of high voltages, except in very small plants. Voltage drop on low voltage systems sooner or later leads to uneconomic cable sizes. High voltage transmission may utilize either overhead or underground techniques.

Underground Cables

There is a number of cases where buried high voltage cable may be economic or desirable for use in small hydro systems. Briefly, these are:

(a) where aesthetic considerations limit the use of overhead lines;

(b) where the cable must be laid under a lake or inlet; and

(c) where conditions and distances are especially favorable to its use.

Conditions which may be favorable to the use of high voltage cables depend largely upon the energy to be transmitted and the distances involved. Underground high voltage cable systems are almost always more expensive than alternative overhead lines, but there are instances where small single and three phase loads have been economically transmitted utilizing airport runway lighting cables. This cable is rated for 5000 volts, and is available in sizes No. 8

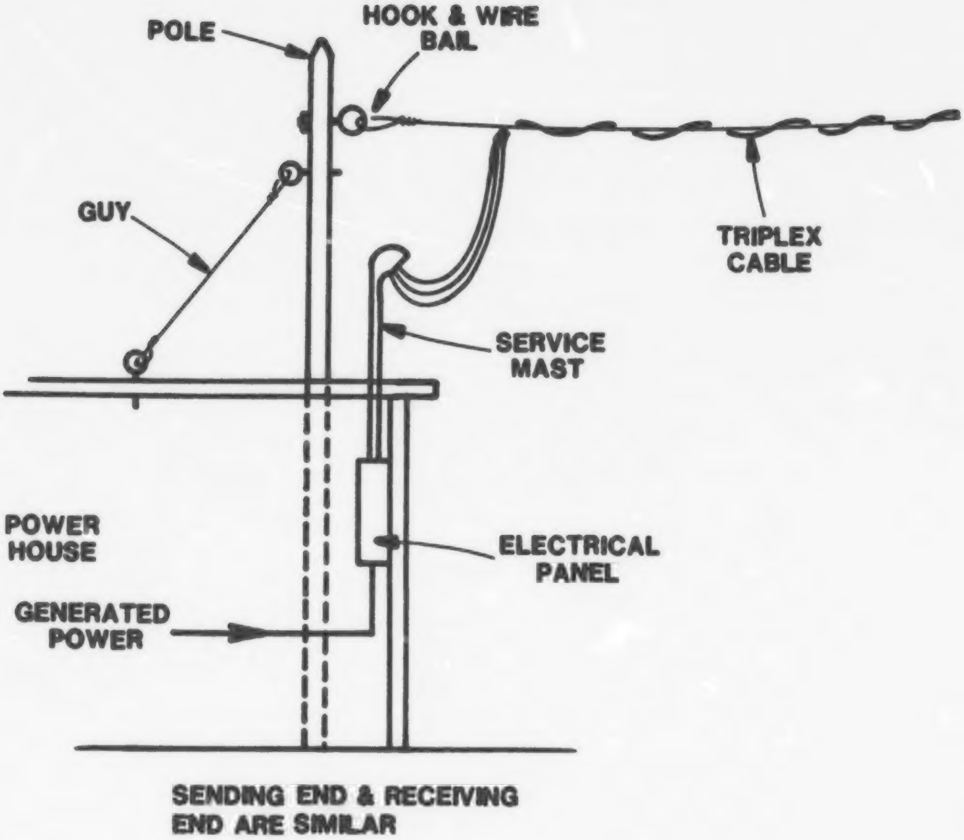

POLE
HOOK & WIRE BAIL
GUY
TRIPLEX CABLE
SERVICE MAST
POWER HOUSE
ELECTRICAL PANEL
GENERATED POWER
SENDING END & RECEIVING END ARE SIMILAR

FIG.4-104LOW VOLTAGE OVERHEAD TRANSMISSION

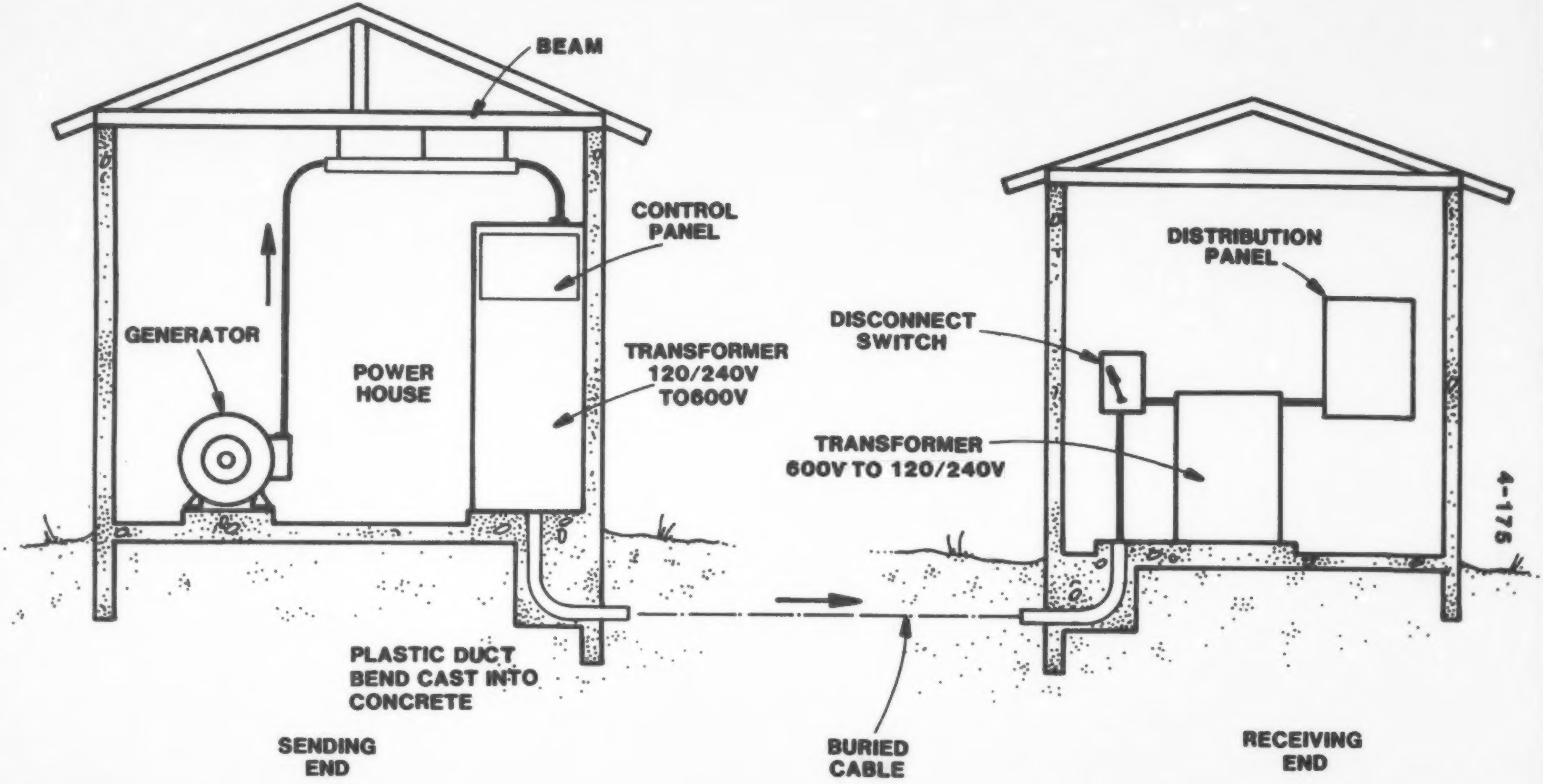

BEAM
CONTROL PANEL
GENERATOR
POWER HOUSE
TRANSFORMER 120/240V TO600V
DISCONNECT SWITCH
DISTRIBUTION PANEL
TRANSFORMER 600V TO 120/240V
PLASTIC DUCT BEND CAST INTO CONCRETE
SENDING END
BURIED CABLE
RECEIVING END

FIG.4-105 EXAMPLE OF LOW VOLTAGE TRANSMISSION SYSTEM 120V/240VTO600V/600VTO120/240V1-PHASE

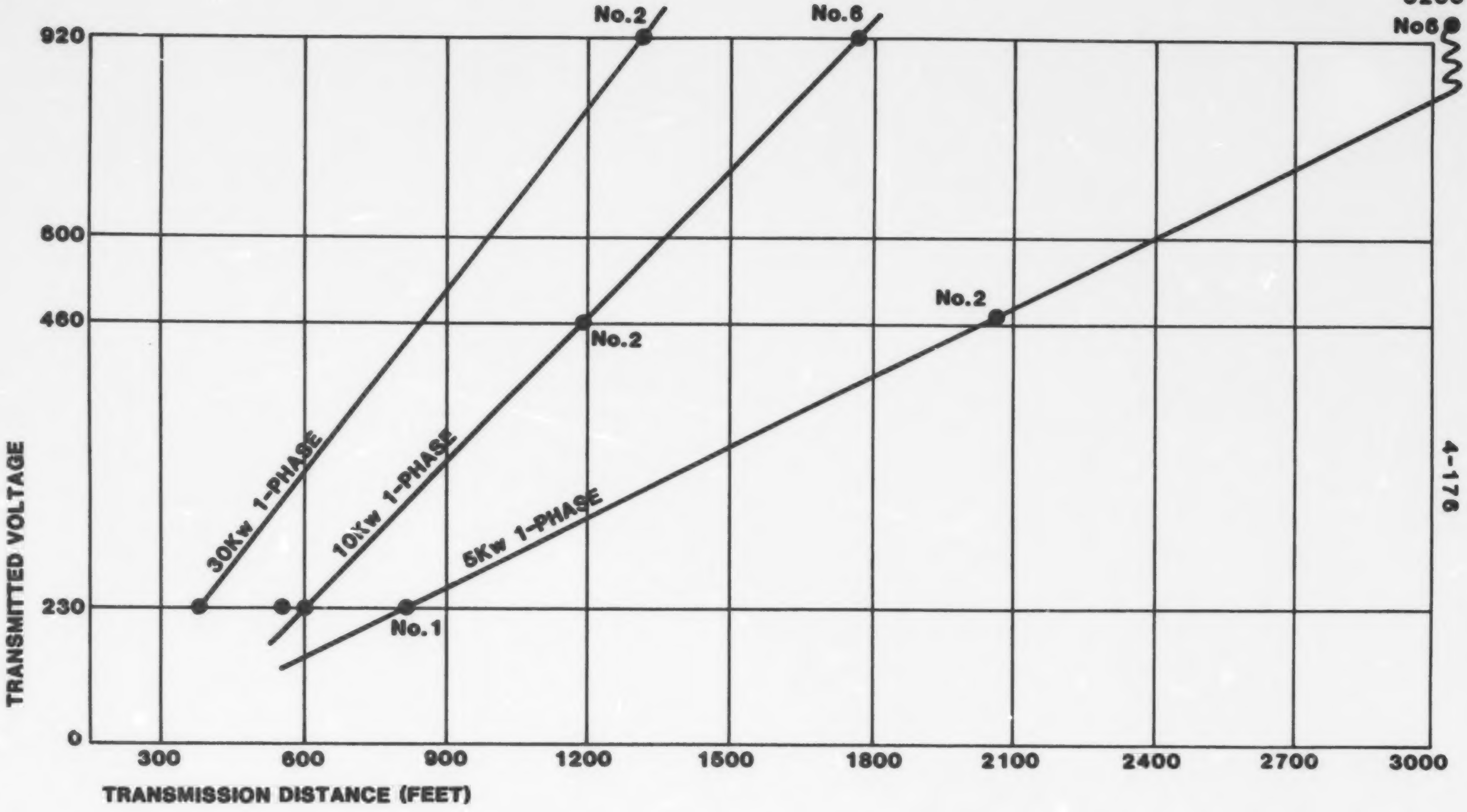

TRANSMITTED VOLTAGE
920
600
460
230
0
TRANSMISSION DISTANCE (FEET)
300
600
900
1200
1500
1800
2100
2400
2700
3000
30Kw 1-PHASE
10Kw 1-PHASE
5Kw 1-PHASE
No.1
No.2
No.2
No.2
No.6
3200'
No6

FIG.4-106

and No. 6, rated respectively, 25 amp and 40 amp for direct buried use. The current rating limits its use to a maximum of 83 kW on 4160 volt single phase, and 140 kW on 4160 volts three-phase at 0.8 p.f.

Cables designed for direct burial are also suitable as a rule for laying under water. They can, for instance, be laid under lakes or coastal inlets, but in the latter case, wire armor is necessary and where the cable enters the water it must be buried to a point below the tide line. The underwater route must be profiled, particularly in coastal waters, to avoid steep drop-offs or submarine canyons which may develop too much tension on the cable. Underwater wrecks must be avoided, and the cable landing should be on a fairly gradual slope. This can be achieved by echo sounding equipment, side scan sonar and other techniques.

A wide range of high voltage cable is obtainable. At one time paper insulated, oil-filled, lead-sheathed cables were exclusively used; and these still are used on important utility circuits. However, solid extruded dielectric cables are now extensively used on voltages up to 35 kV or more. Solid dielectric cable above 5000 volts, must be terminated with epoxy resin termination kits made to suit the cable size and voltage. There are indoor and outdoor types. Cable manufacturers and suppliers will recommend the most economic cable for any given situation.

At one time, cables were usually installed in ducts, but this is no longer necessary except when leaving and entering buildings. At those locations, plastic duct can be installed in the floor slab. A range of plastic duct is available for electrical installations. Where high voltages are concerned, cable size for either direct buried cables or submarine cables can be approximated using the voltage drop tables provided, but there are minimum conductor sizes depending upon the voltage rating. For relatively long cables, say over a half-mile, refer to the manufacturers for size and voltage drop. Do not attempt to install high or low voltage cables under large streams or rivers, as they are likely to be swept away during the spring run-off.

Cable Trench

Install cable inside plastic pipe under roads, and increase depth to three feet.

Overhead High Voltage Lines

Conductors

Almost all present day transmission lines use aluminum conductor steel wire reinforced (ACSR). The steel core provides high tensile strength, while the aluminum wires carry the current.

Operating Voltages

"Standard voltages" vary somewhat, depending on utility standards and historical factors. Commonly used modern voltages are 2400V, 4160V, 7200V, 12470V, and 14400V.

Choice of Voltage

An often used rule is to allow 1000 volts per mile, but actual choice depends upon cost and standard voltage rating of transformers.

ACSR Tables,for single and three phase lines

Tables have been prepared for small hydro use based on ACSR conductors. The tables are useful up to 500 kVa, and is limited to No. 4 and No. 2 ACSR.

ACSR Conductor Sizing Chart
Single Phase High Voltage 0.8 p.f.

Miles	1	2	3	
kW				
5	4	4	4	
10	4	4	4	2300 V
15	4	4	4	
25	4		2	
37 1/2	4	2	4	4160 V
50	4	4	4	

Basis: Electrical Transmission and Distribution Reference Book, Westinghouse Electric Corporation.

ACSR Conductor Sizing Chart
Three Phase High Voltage 0.8 p.f.

Miles	1	2	3	4	5	6	
kW							
30	4	4	4	4	4	4	
45	4	4	4	4	4	4	4160 V
60	4	4	4	4	4	4	
75	4	4	4	4	4	2	
112 1/2	4	4	4	2	4	4	6900 V
150	4	4	2	4	4	4	7200 V
225	4	4	4	4	2	2	
250	4	2	4	2	2	4	12470 V
300	4	4	4	4	4	4	13200 V
500	2	2	2	4	4	4	14400 V

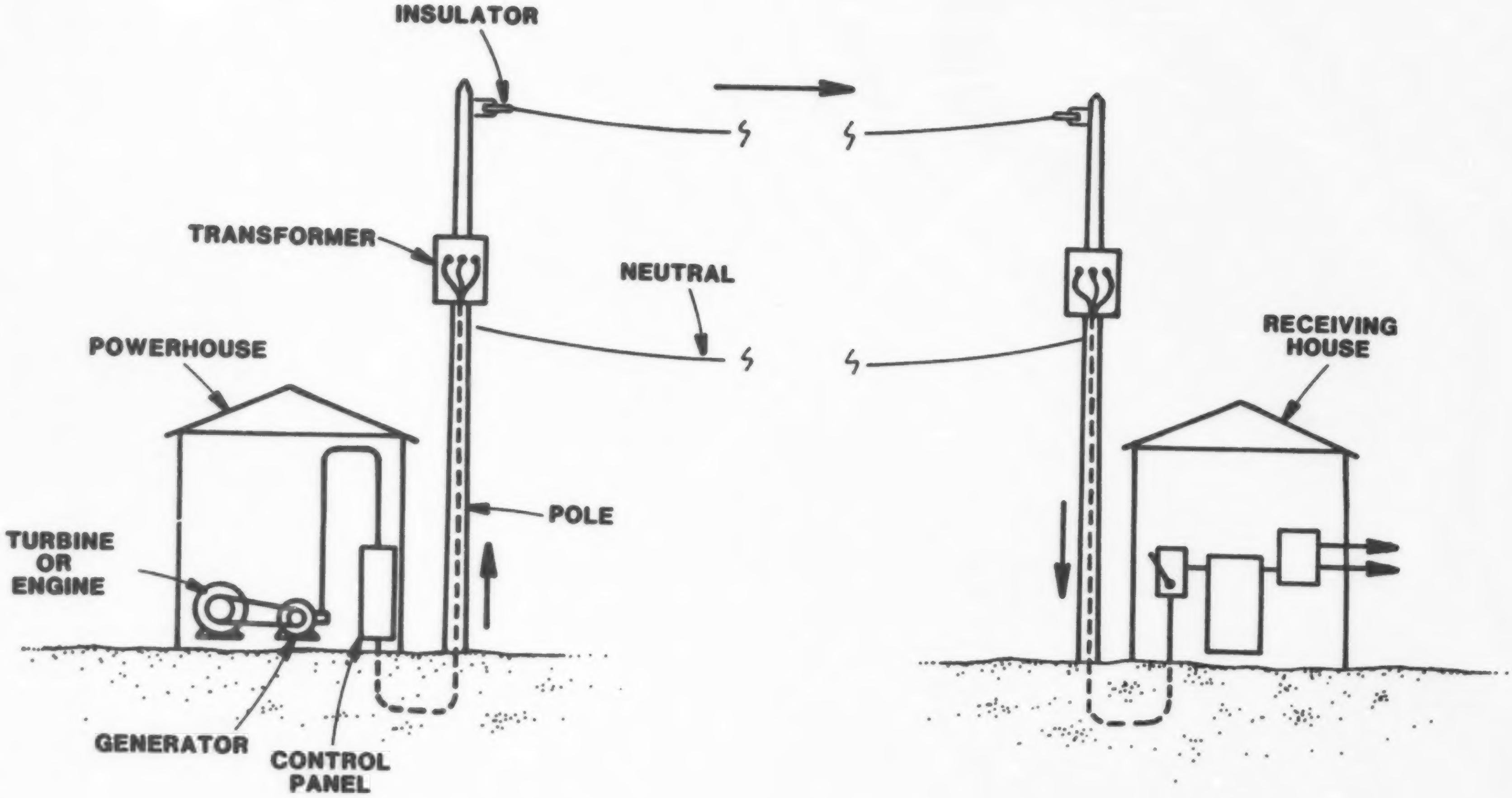
Explanation of the ASCR Sizing Chart

ACSR (Aluminum Conductor Steel Reinforced) is universally used for transmission line conductors. The charts are based on a maximum of five percent regulation. On a transmission line, regulation means the percentage by which the receiving end voltage will rise when the load is removed. The supply end voltage therefore must be somewhat higher than the receiving end voltage in order to maintain standard voltages at the load. In the sizing chart, five percent regulation, or voltage drops no load to full load, will only occur when the conductor is near the boundary where an increase in either wire size or voltage is indicated. Otherwise, the regulation will be less than five percent.

Three phase transmission requires three isolated conductors supported on pin type porcelain insulators. Single phase lines require only one isolated conductor, with the return wire mounted on uninsulated wire clips at each pole and grounded at each end. Conductors smaller than No. 4 ACSR are not likely to withstand ice and wind loads normally encountered in B.C. If the line is particularly exposed to wind load and/or freezing rain, the minimum should be No.2 for light lines and 1/0 for larger systems. There is little difference in cost between 2300 volt, 4160 volt, and 7200 volt construction, whilst 14400 volt lines will be marginally more expensive.

Line Routing and Construction

The routing and construction of overhead lines is a specialized art involving a wide range of standards, materials and methodology. To give some conception of techniques, general information is provided here. This information is derived from B.C. Hydro and Power Authority, Electrical Distribution Standards ES43, and from the "Linesman's Handbook", Edwin B. Kurtz, McGraw-Hill, New York, 1955.


INSULATOR
TRANSFORMER
NEUTRAL
POWERHOUSE
RECEIVING HOUSE
POLE
TURBINE OR ENGINE
GENERATOR
CONTROL PANEL

4-107 EXAMPLE OF HIGH VOLTAGE TRANSMISSION
480V TO 2300V/2300V TO 120/240V 1-PHASE

Insulators

Insulators will normally be pin type, rated for the insulation level of the line. Conductors on 2300 volt to 14440 volt systems often are horizontally spaced on a wood crossarm, but a triangular layout using angle brackets is also used and saves the cost of crossarms and braces. The chart gives the conductor spacing to be used.

Spacing Insulators and Arrestors*

Line Voltage	Insulation Level (Bil.)	Arrestor	Minimum Crossarm Spacing inches
2300	45	3 Kv	24
4160	60	4.5	24
6900	75	7.5	30
7200	75	9	30
12470 to 14400	95	15	30

* distribution class equipment.

Poles

For most small lines, 40-foot wood poles spaced 150 feet to 250 feet are sufficient. Western red cedar or lodgepole pine are preferred. Poles should be butt treated for use in the interior, but in coastal areas, full length preservative treatment should be done. Poles are graded according to strength into 14 classes. The lower the number, the higher the strength. Normally, Classes one through six are commercially available. For the size of line under discussion in this manual, Class four or five will suffice for three-phase, and Class five or six for single phase.

It is usual to measure and mark the setting depth on poles, and to install the crossarms and insulators prior to setting the pole. Setting depth, by rule of thumb, is 10 percent of its length plus two feet. In rock, 10 percent only may be used. Poles set in marshy ground can be set in a 45 gallon drum with the bottom at pole setting depth. The drum is backfilled with weak mix concrete and the remaining excavation backfilled with rock or coarse gravel. Where grass fires are expected, pile up around the pole base, a cone of rock about three to four feet above ground.

Class		3	4	5	6
Top Circumference inches		22.8	20.8	18.9	16.9
Length Ft	Metres	Minimum Circumference 6 feet from base (in)			
36.3	11	38.6	35.8	33.5	30.7
41.25	12.5	41	38.1	35	32.6
46.3	14	43	39.7	37	34.2
51.1	15.5	44.8	41.7	35.6	35.5

Many poles will need to be guyed, especially at line angles and dead ends. Guys consist of galvanized wire rope 5/16" or 3/8" diameter is suitable for light road lines. Guying must be done before installation of the conductors. After the line ages for a period of two to three years, guys may have to be tightened or loosened, and occasionally new ones may have to be added to pull leaning poles into line. The line will eventually stabilize and will require very little maintenance other than the occasional tree lopping. Stumps or fallen trees should not be used as the guy will eventually slacken; however firm rocks are acceptable.

Conductor Sagging

All overhead lines must be sagged by a calculated amount in order to compensate for extremes in temperature. At low temperatures the line contracts, raising the stress in the conductor. Similarly, at high temperatures the line will expand, affecting clearances. The amount of sag depends upon ruling or average span, actual span, conductor size and material, temperature extremes, stringing tension, and expected ice and wind load. Sag charts are prepared for local conditions and must be strictly adhered to. Sag charts can be obtained from cable suppliers and utility companies. It is very important to allow for minimum winter temperatures including ice and winter loads in your area. B.C. Hydro can supply sag charts for various areas in British Columbia.

Stringing Conductors

Conductors are always pulled off the reels directly into position on the pole. Stringing sheaves are lashed to or clamped to the crossarms, and the conductors are pulled out over the line by means of a winch. When the conductors are on the crossarms, they are tied onto the insulators one by one while sagging proceeds. No. 4 and No. 2 can usually be pulled directly in on the crossarms, without the use of pulleys.

Standards

Refer to CSA standard C22.3 No. 1 - 1976, Overhead Systems and Underground Systems. This publication gives clearances and other necessary information for the installation of overhead lines and buried cables.

Route Selection

These are the general rules:

1. Select the shortest route practicable.
2. Run parallel to roads whenever possible; accessibility significantly lowers cost of construction, inspection, and maintenance.
3. Follow property lines wherever possible rather than cutting across fields, as this minimizes easements and does not interfere with agricultural use.
4. Route in the direction of known future loads so that future extensions will be less expensive.
5. Avoid swamps or bottom land. Line construction is more costly in poor ground, especially when the ground is liable to flooding.
6. Avoid existing aerial telephone lines. Running alongside telephone lines may cause interference on the telephone line.
7. Avoid, as far as possible, routes which necessitate heavy timber clearing or rock blasting.
8. Cross roads, railroads, and other rights of way at right angles. Permission to do so must be obtained.
9. Keep the line as level and regular as possible.
10. When road access is provided to the power plant (this should be done whenever possible), build the power line along the road.

Right of Way Clearing

Clearing for power lines varies according to the likelihood of trees falling on the line. Where this is not a problem, small trees are usually clear cut to a width of 25 feet or so. Where there are tall trees, wider rights of way must be cleared. This is not always justifiable on small rural lines, which will survive quite well if tree topping and falling is done regularly. It is particularly important to cut all danger trees, which can cause much damage should they fall on the line.

Surveying

The line must be surveyed and a map made. All pole locations must be staked, and elevations established so that design work and sag calculations can be made.

Professional Assistance

Transmission lines and major cable installations require professional design. Consultants, engineers, or power line contractors can provide the necessary assistance, but you can do much of the preliminary work yourself. For instance, you can usually establish a preliminary route, and begin negotiating with local property owners, the Highways Department, the Forest Industry, and so on. Chapter Five provides information on legal and statutory requirements.

Grounding

All neutrals, whether low voltage or high voltage, must be reliably grounded. For instance, on single phase, high voltage lines, the pole transformer case, the arrestor, and the insulated neutral conductor must be grounded by means of a driven ground rod at the pole base. For units up to 100 kW, a No. 4 copper wire is satisfactory. Similarly, for three phase, high voltage systems, ground the arrestors and transformer cases. Generator neutrals will be grounded in the main control panel. A separate ground must be run to the generator frame. Low voltage transformers with 120/208 volt secondary will have the neutral grounded in the distribution panel. The transformer case must also be grounded.

Installing in the power house a ground bus bar consisting of a 12 inch length of 1/4 inch by 2 inch copper bar. All equipment grounds can be bolted with connectors to this ground bar so that they can be disconnected for testing. The ground bus should be connected to at least two driven ground rods about 15 feet apart. Ground rods are galvanized steel or copper, 5/8 inch by 8 feet. See the Canadian Electrical Code C22.1 Section 10, 14, and 30, for requirements.

Sketches

The following sketches are included to show typical installation practice:
(a) Low voltage installation; Figure 4-105
(b) High voltage installation; Figure 4-107

The following standards are reproduced here as examples of overhead line construction, Figure 4-110 through Figure 4-117.

4.28 TRANSFORMERS

Transformers are necessary when you wish to change one A.C. voltage to higher or lower voltage. Transformers have two windings, either of which can be used as primary or secondary. For small hydro use, there are three basic types:

(a) oil filled, pole mounted outdoor;
(b) oil filled padmount; and
(c) dry type, indoor.

Pole Mounted Transformers

These are oil insulated transformers intended for outdoor installation, and have one or more porcelain bushings (insulators) on the case. They are usually pole mounted up to about 75 KVA. Transformers above 75 KVA are often mounted on a platform or rack supported on two or more poles, while sizes over about 200 kW are installed on concrete bases on the ground. It is easier to mount small transformers on a rack structure owing to the greater amount of space available for fuses, connections, and arrestors.

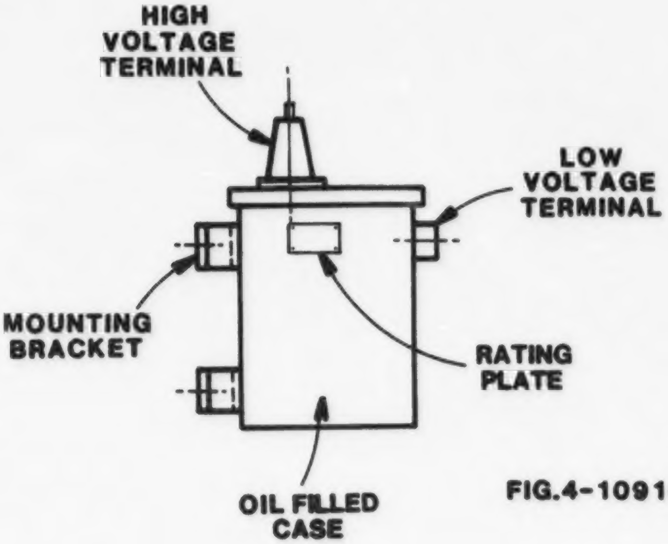
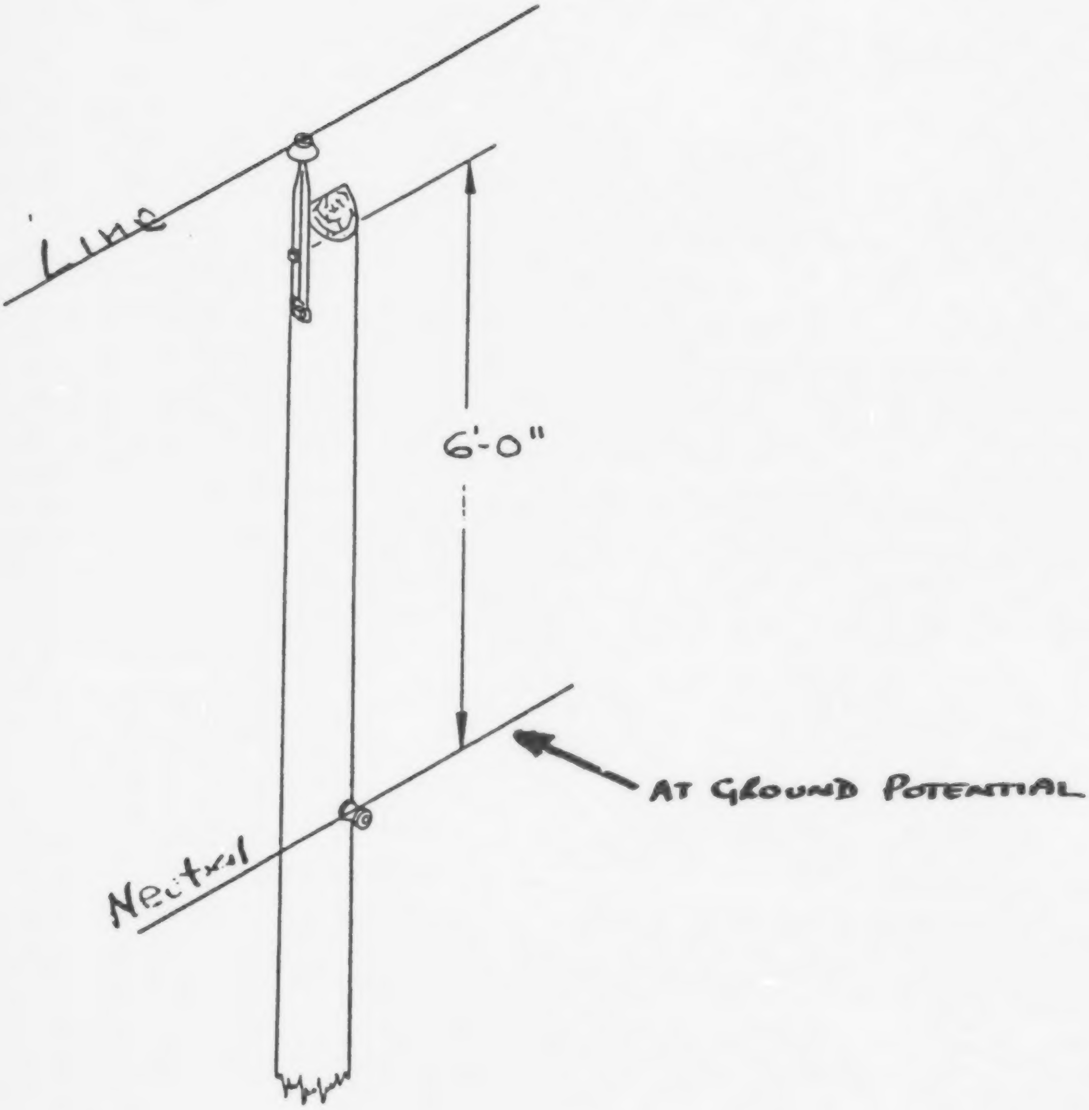
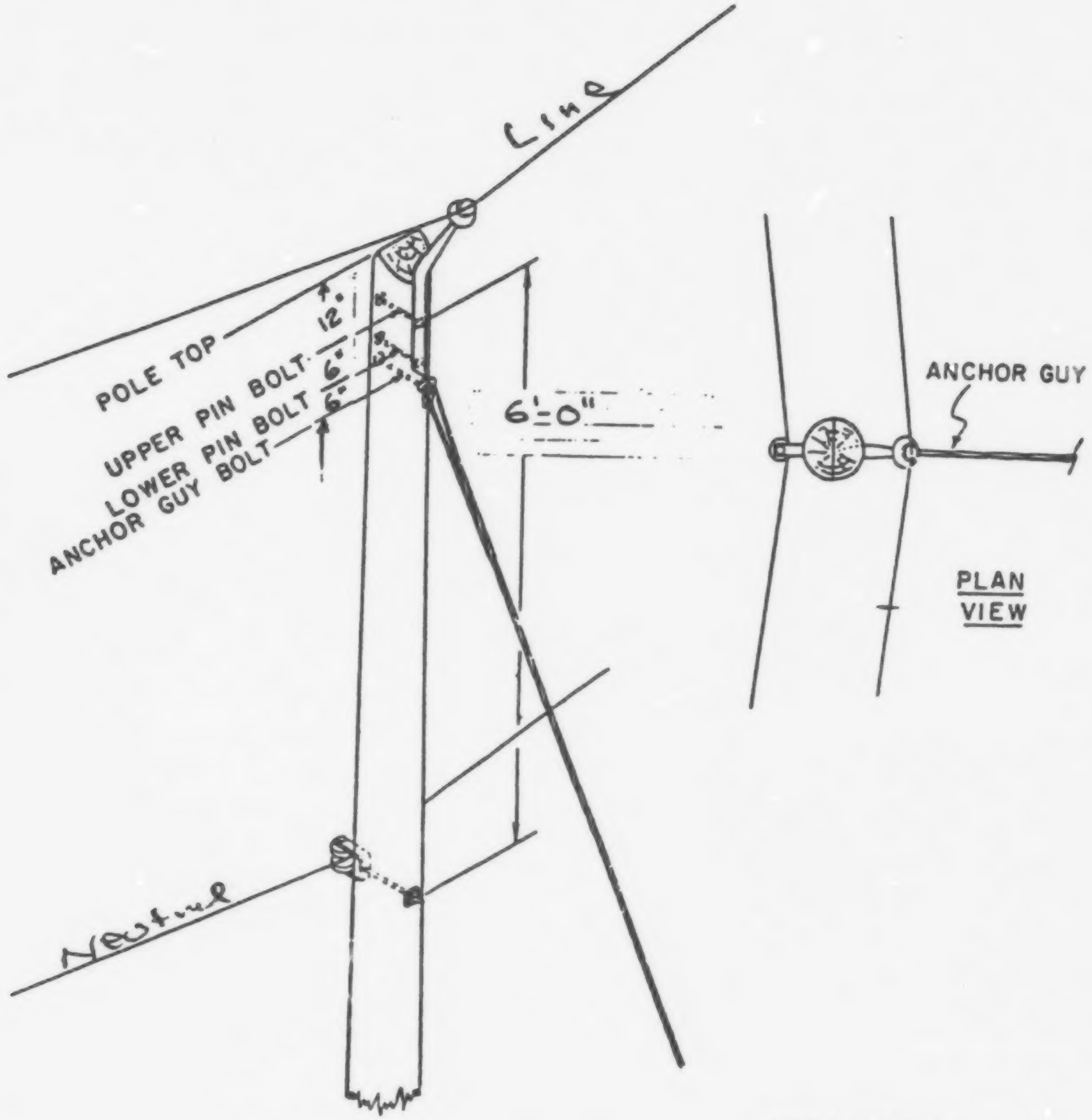

HIGH VOLTAGE TERMINAL
LOW VOLTAGE TERMINAL
MOUNTING BRACKET
RATING PLATE
OIL FILLED CASE

FIG.4-1091-PHASE POLE TRANSFORMER


Line
6'-0"
Neutral
AT GROUND POTENTIAL

NOTE:-THIS STRUCTURE MAY NORMALLY BE USED UNGUYED FOR ANGLES UP TO 5°.

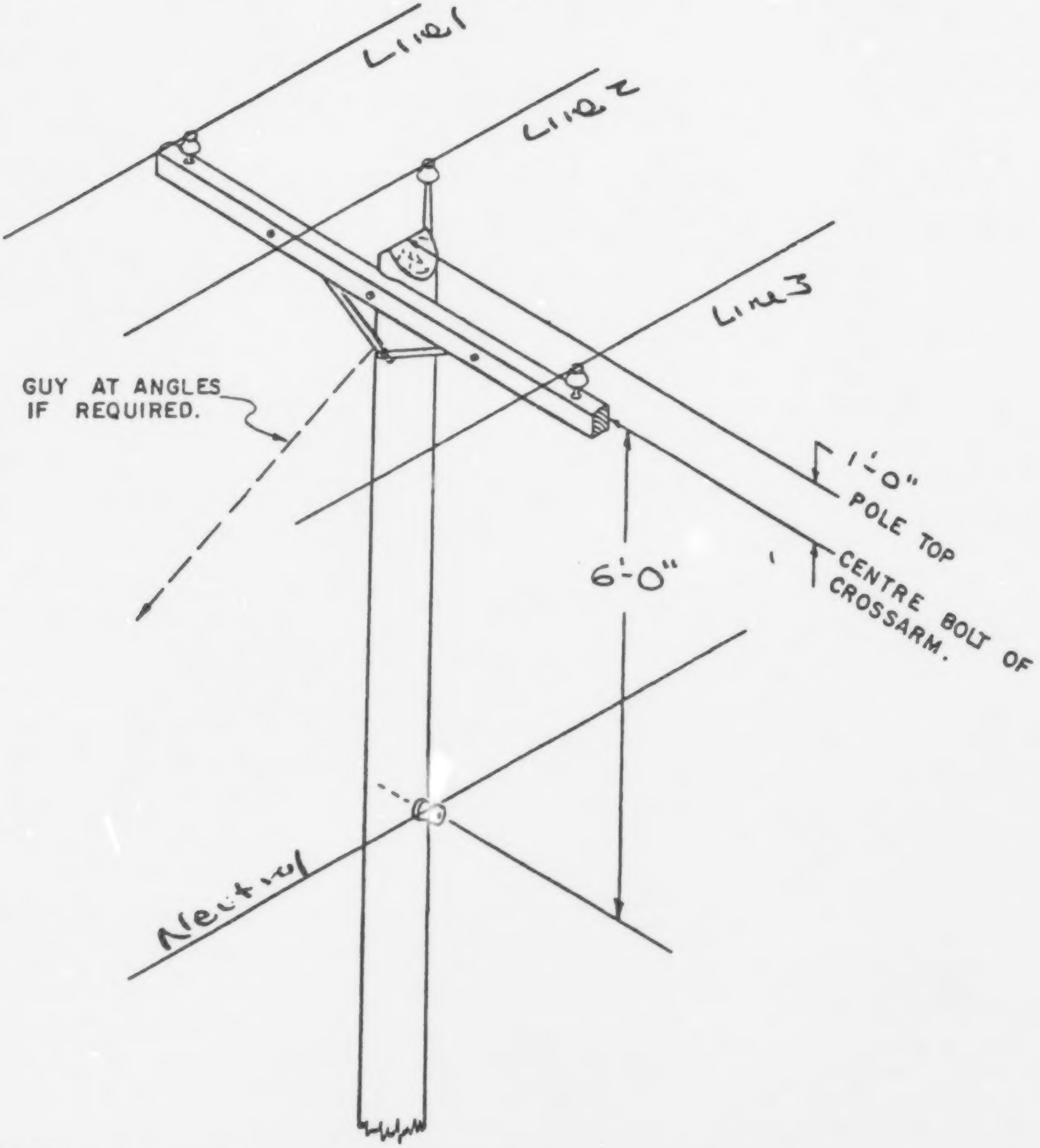
FIG 4-110
SINGLE PHASE POLE LINE


Line
POLE TOP
UPPER PIN BOLT
LOWER PIN BOLT
ANCHOR GUY BOLT
12"
6"
6"
6'-0"
Neutral
ANCHOR GUY
PLAN VIEW

APPLICATION

A.C.S.R.	ANGLE
4, 2	5° – 45°
1/0 TO 266.8	5° – 30°

Fig 4-111


Line 1
Line 2
Line 3
GUY AT ANGLES IF REQUIRED.
1'-0"
POLE TOP
CENTRE BOLT OF CROSSARM.
6'-0"
Neutral

NOTES:

COMMPRESSION BRACE TO REPLACE FLAT BRACES FOR CONDUCTOR LARGER THAN 2/0.

. THIS STRUCTURE ALSO SUITABLE FOR ANGLES 0° TO 5°, WITH GUY AS REQUIRED.

FIG 4-112

Padmount Transformers

Padmount transformers are oil filled outdoor units designed for use with high and low voltage cable connections. These are often used at commercial premises, and are a safe and effective means of stepping up voltage for high voltage cable transmission. They are installed on a concrete based on the ground.

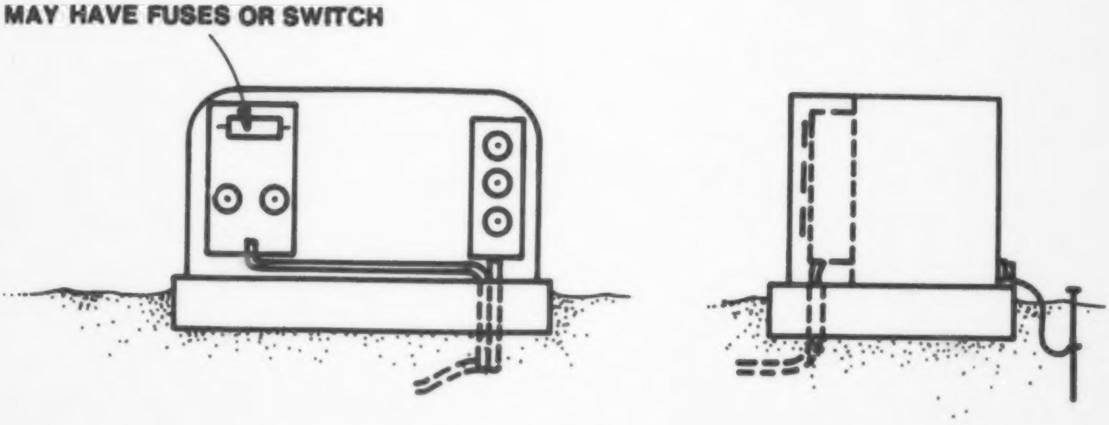


FIG.4-113PADMOUNT TRANSFORMER

Dry Type Transformers

Dry type transformers contain no oil or other fluid and are intended for indoor installation. They are useful for stepping down industrial voltages to low service voltages such as 600-120/208 volt or 440-120/240 volt. Dry type transformers contain bare conductors and connections inside the case, and are therefore not recommended for use inside small power houses where leaks and spraying water are potential hazards. This is especially true when the transformer is used to step generator voltage up to 2300 volts or more for high voltage transmission.

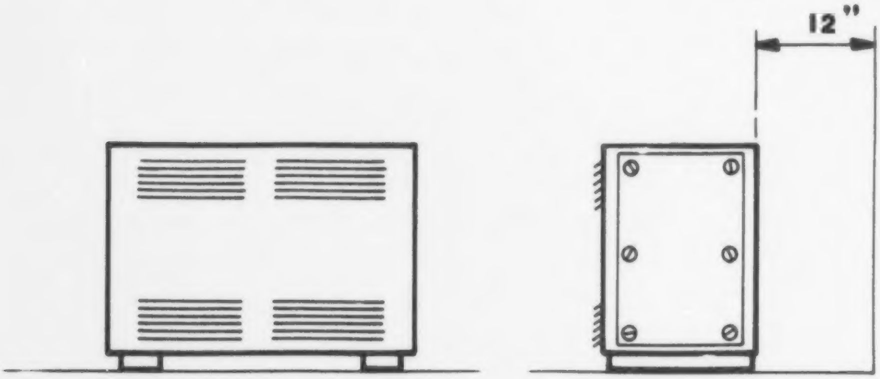


FIG.4-114DRY-TYPE INDOOR TRANSFORMER

Transformer Standard Sizes

Single and three phase transformers are available in a wide selection of ratings, voltages, and connections for all types.

Table of Distribution Transformer kVa Ratings, Dry and Oil

Single Phase	Three Phase
3	15
5	30
10	45
15	75
25	112½
37½	150
50	225
75	300
100	500
167	750
250	1000

(Higher ratings are available)

CONVERTING VOLTS AND AMPS TO kW AND kV•A

3 PHASE kV•A—AMPERE TABLE LINE AMPS AT COMMON LINE TO LINE VOLTAGES

RATING												
kV•A	kW*	200V	208V	220V	230V	240V	380V	400V	415V	460V	480V	600V
6.3	5	18	17.5	16.5	15.7	15.2	9.6	9.1	8.7	7.9	7.6	6.1
9.4	7.5	27.1	26.1	24.7	23.5	22.6	14.3	13.6	13	11.8	11.3	9.1
12.5	10	36.1	34.7	33	31.4	30.1	19.2	18.2	17.4	15.7	15.1	12
18.7	15	54.2	52	49.5	47.1	45	28.8	27.3	26.1	23.6	22.5	18
25	20	72.2	69.5	66	62.8	60.2	38.4	36.4	34.8	31.4	30.1	24
31.3	25	90.3	87	82.5	78.5	75.5	48	45.5	43.5	39.2	37.8	30
37.5	30	108	104	99	94	90.3	57.6	54.6	52.2	47.1	45.2	36
50	40	144	139	132	126	120	77	73	70	63	60	48
62.6	50	181	173	165	157	152	96	91	87	79	76	61
75	60	217	208	198	188	181	115	109	104	94	91	72
93.8	75	271	261	247	235	226	143	136	130	118	113	90
100	80	289	278	264	251	240	154	146	139	126	120	96
125	100	361	347	330	314	301	192	182	174	157	150	120
156	125	451	433	413	392	375	240	228	218	196	188	150
187	150	542	520	495	471	450	288	273	261	236	225	180
219	175	632	608	577	549	527	335	318	305	275	264	211
250	200	722	694	660	628	601	384	364	348	314	301	241
312	250	903	866	825	785	751	480	455	435	393	376	300
375	300	1083	1040	990	942	903	576	546	522	471	451	361
438	350	1264	1220	1155	1099	1053	672	637	609	550	527	422
500	400	1444	1390	1320	1256	1203	770	730	696	628	602	481
625	500	1805	1735	1650	1570	1504	960	910	870	785	752	602
750	600	2166	2080	1980	1883	1803	1150	1090	1044	942	902	721
875	700	2527	2430	2310	2197	2104	1344	1274	1218	1099	1052	842
1000	800	2888	2780	2640	2511	2405	1540	1460	1392	1256	1203	962
1125	900	3249	3120	2970	2825	2709	1730	1640	1566	1413	1354	1082
1250	1000	3610	3470	3300	3139	3009	1920	1820	1740	1570	1504	1202

*At 0.8 Power Factor

$$kW = \frac{\text{Volts} \times \text{Amps} \times 1.73 \times \text{Power Factor}}{1000}$$

FIG 4-115

HOW TO USE

A customer states an electrical requirement for 500 amps, 3 phase at 460 volts, line to line. Looking at the table, read down the 460 V column to an ampere rating which meets the customer's requirements (in this case 550). Read across for kWs. In this case you find 350 kW.

Common Features

Regulation

The secondary voltage of a transformer drops on load, owing to internal winding losses. This is called 'regulation', and amounts to 1.5 percent at unity power factor, to 7 percent at 0.8 lagging power factor. Efficiency is very high, varying from 96.5 percent on very small units to 99.4 percent on very large ones.

Taps

Taps are a means to provide voltage adjustment on transformers to compensate for regulation and voltage drop on feeders. The most commonly selected tap arrangement is the manually adjusted off-load type, consisting of four 2 1/2 percent steps away from the nominal primary voltage rating. Tap positions are numbered one through five, with No. 1 giving the greatest effective primary turns and the lowest secondary voltage.

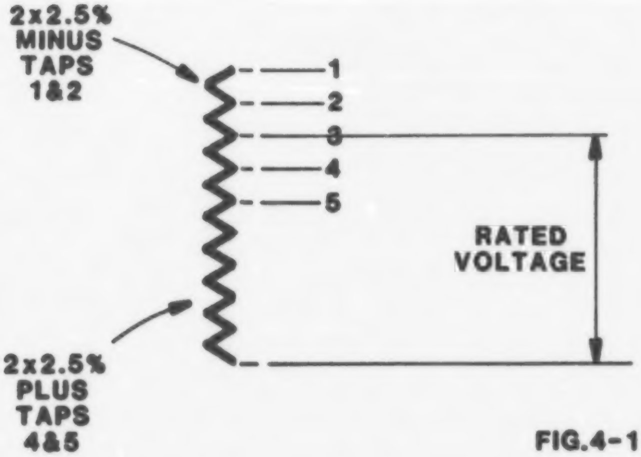


FIG.4-116TRANSFORMER TAPS

On oil filled units, an off-load tap switch is usually supplied, while dry type units have a terminal block. Tap switches must never be operated on an energized transformer.

Polarity

Transformer terminals are marked since transformers have "instantaneous polarity" which affects external connections.

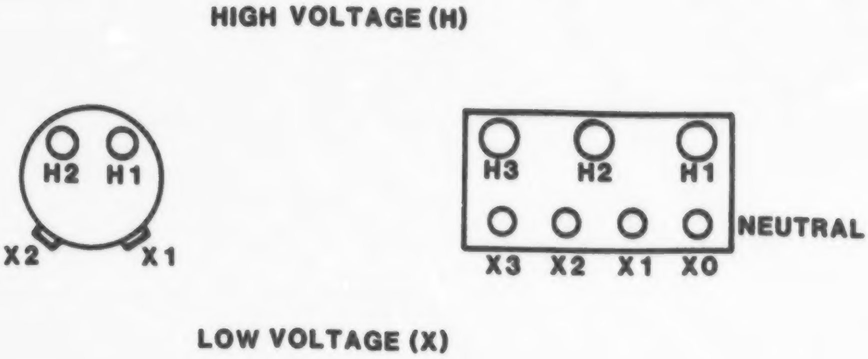

HIGH VOLTAGE (H)
H2
H1
X2
X1
H3
H2
H1
NEUTRAL
X3
X2
X1
X0
LOW VOLTAGE (X)

FIG.4-117TRANSFORMER POLARITY

Single Phase Connections

Single phase connections are simple, since they do not involve star or delta connections. The following diagram illustrates a single phase transmission system. It is not necessary to connect the generator neutral to the step-up transformer, since the neutral can be provided by the load end transformer. This leads to a simple and economic transmission line.

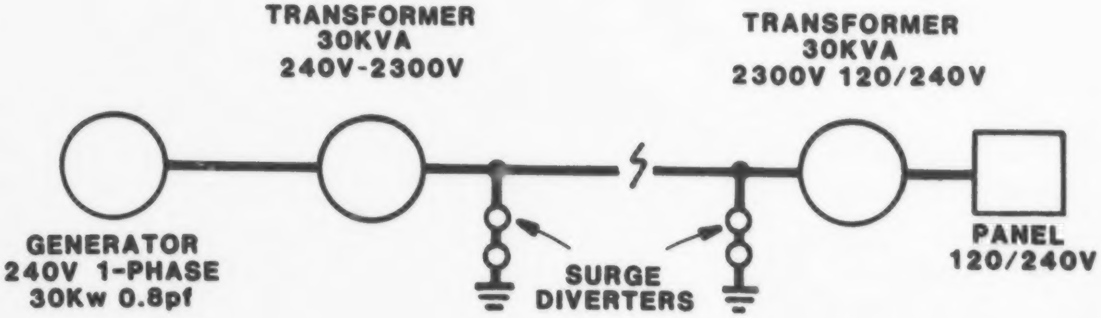

TRANSFORMER
30KVA
240V-2300V
TRANSFORMER
30KVA
2300V 120/240V
GENERATOR
240V 1-PHASE
30Kw 0.8pf
SURGE
DIVERTERS
PANEL
120/240V

FIG.4-118 1-PHASE SYSTEM

Further discussion on connections appears under Single and Three Phase Systems.

Three Phase Connections

A great many connections are possible, but for small hydro use, one will cover most requirements.

Refer to Figure 4-120 thru 4-122.

For technical reasons involving harmonics and grounding, one delta and one star connection are preferable in a three phase transformer or transformer bank. On voltages over 7200 volts, some advantages accrue to using Y-Y high voltage connection and transmission lines. Diagram 4-121 shows a star connected generator connected to a star delta step-up transformer. At the load end, a delta-star transformer steps the voltage down to the three phase service voltage.

Transformer Protection

All transformers require overload and short circuit protection. This is achieved by means of fuses and/or circuit breakers depending upon details of the system. In small hydro systems, the transformer will normally be protected by the main generator circuit breaker, thus:

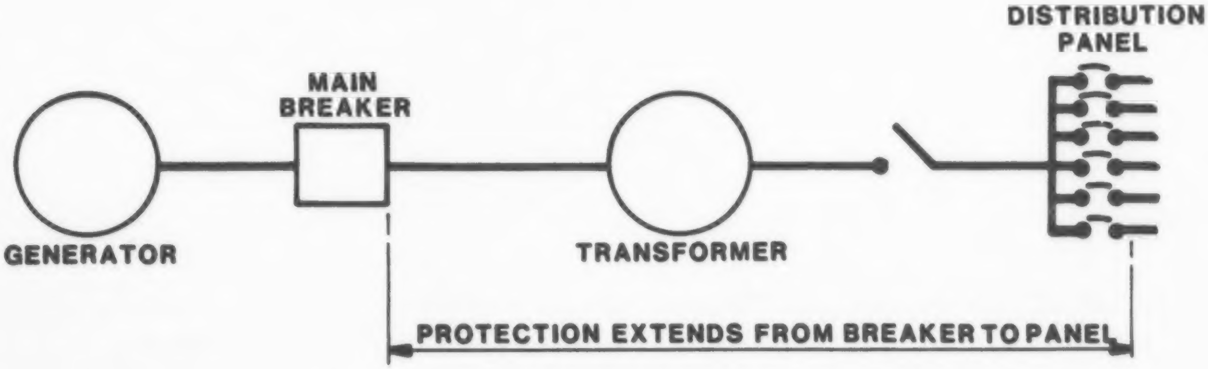


FIG.4-119TRANSFORMER PROTECTION

Surge protection is also necessary where transformers are connected to either high voltage lines or underground cables. Surges can be induced by nearby or direct lightning strikes, and to a much lesser extent by switching. Buried cables are vulnerable to lightning surges and should have surge arrestors positioned close to the

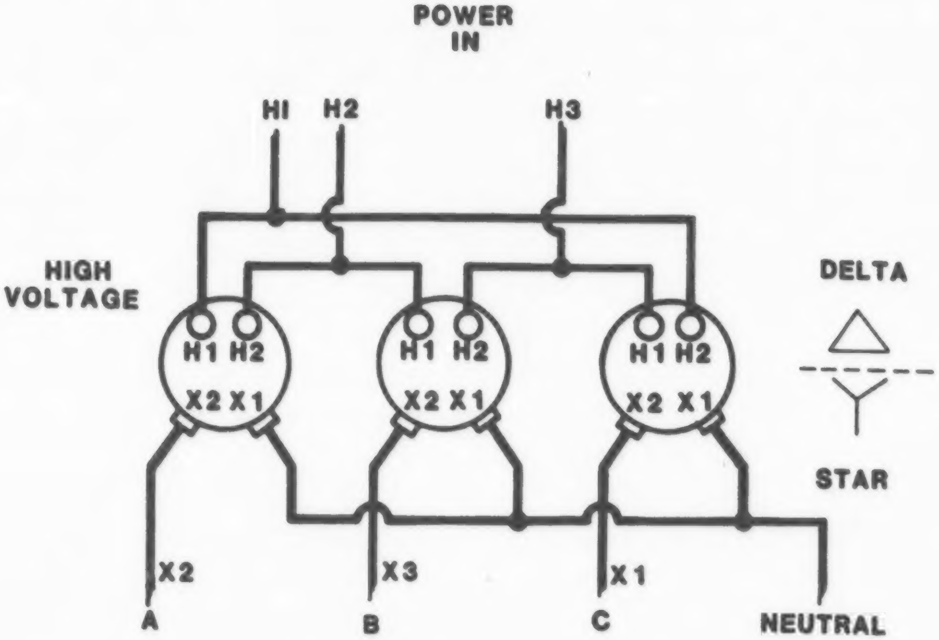

POWER
IN
HI
H2
H3
HIGH
VOLTAGE
H1 H2
X2 X1
H1 H2
X2 X1
H1 H2
X2 X1
DELTA
STAR
X2
A
X3
B
X1
C
NEUTRAL

FIG.4-120STAR DELTA TRANSFORMER BANK

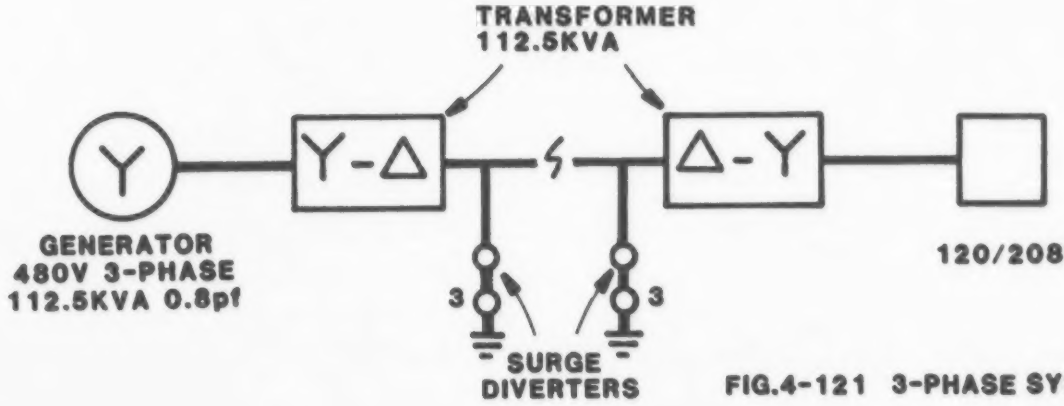

TRANSFORMER
112.5KVA
Y
Y-Δ
Δ-Y
GENERATOR
480V 3-PHASE
112.5KVA 0.8pf
3
3
SURGE
DIVERTERS
120/208V

FIG.4-121 3-PHASE SYSTEM

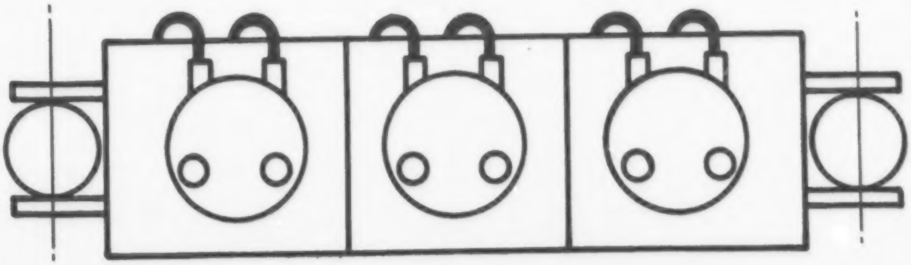


FIG.4-122 3-PHASE TRANSFORMER BANK
(3 INDIVIDUAL 1-PHASE UNITS)

transformer in the case of pole mounted units, or inside the case for padmount units. Where dry type units are used in connection with voltages greater than 600 volts, the high voltage side should be protected. In this case, the arrestor must be placed as close as possible to the high voltage connections with a short connection to the transformer case ground.

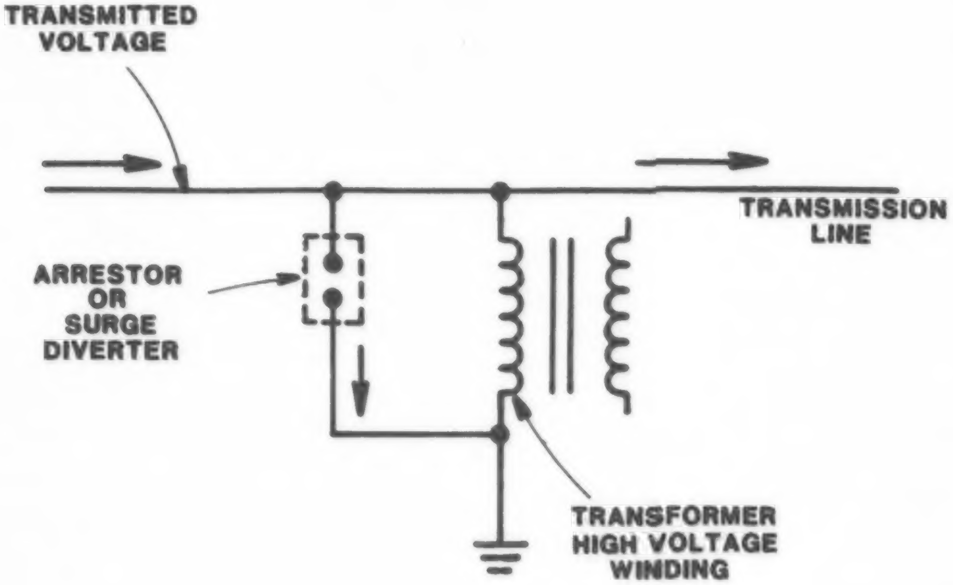


FIG.4-123VOLTAGE SURGE PROTECTION

Determination of Rating and Specification

When the transformer carries the whole of the generator output, the transformer rating must match the generator. Otherwise, the transformer is sized to suit the intended load.

Example 1

Generator 30 kW, 0.8 pf single phase, 120/240 V. Transformer to be an outdoor oil filled, pole mounted unit, feeding a 2300 volt line.

No. & Type: One single phase ONAN pole mounted transformer each end
No. of busings (HV insulator: One
Primary voltage: 120/240V
Secondary voltage: 2300V (or 4160V)
Taps: 2 x 2 1/2% up, plus 2 x 2 1/2% down
Standard: CSA approved
kVa - 30
Arrestor: 3 kV or (5 kV) distribution class.

Note: The designation ONAN means "oil insulated natural air circulation cooled", and is normal in small outdoor transformers. CSA approval includes insulation requirement and other many technical features. See "Transmission" for discussion on connections and other items.

Example 2

Generator 112 1/2 kW, 0.8 pf., 480 V, 3 phase. Transformer is to feed a three phase 4160V line. Three single phase transformers to be grouped on three phase.

No. & Type: Three single phase ONAN pole mounted transformers each end.

Each transformer:
No. of H.V. bushings: Two per transformer.
3 transformers: 480V primary 4160V secondary
3 transformers: 4160V primary 120V secondary
Taps: 2 x 2 1/2% up and 2 x 2 1/2% down
kVa: 37 1/2 (37 1/2 x 3 = 112 1/2 kVa)
Standard: CSA approved
Arrestor: 5 kV distribution class

Transformers at the receiving end are similar, rated for the primary high voltage and whatever secondary voltage is required.

Note 1: With transformer taps at each end, considerable voltage adjustment is available.

Note 2: If a transformer line has only one high voltage bushing it can only be connected line to ground. If it has two high voltage bushings, it can be connected line to line.

Maintenance

Oil filled transformers below 500 kVa do not require maintenance. Dry type units should be located where they can freely ventilate, and the connections should periodically (two to three years) be examined for overheating caused by corrosion. Remove the access panels and remove dust and dirt every three to four years.

Service Life

Transformers last almost indefinitely, provided they are not continuously overloaded or damaged by lightning surges. Many cast-iron cased transformers built in the 1920's or even earlier are still in service on many utilities.

Standards

Most engineers will specify discretional standards, such as NEMA, ANSI, or EEMAC for larger transformers. For small units below 250 kVa or so, it is sufficient to specify CSA approval only.

Safety

Do not work on live transformers. When cleaning dry type transformers use a soft brush and a vacuum cleaner. Do not overtighten connections.

Professional Advice

Prior to purchase, discuss with professionals or transformer suppliers your requirements and your intended installation and connection of transformer.

4.29 SINGLE AND THREE PHASE SYSTEMS

The vast majority of domestic and small commercial premises are supplied with single phase power. Loads typically vary from a few kilowatts to a maximum of around 30 kIlowatts. Over that size, switching three phase often becomes more economic, especially where an appreciable motor load is to be serviced. Single phase systems are 115/230 volts.

Single Phase Basic Connection

All branch circuits for lighting, receptacles, and motors below a half horsepower, should be connected across the line-to-neutral 115 volt supply, while larger loads such as heating or large motors should be connected across the 230 volt supply.

Single phase generators are common up to 30 kW, but there are a few larger installation over 30 kW. Many manufacturers will supply a three phase generator arranged to supply 115/230 volts using part of the winding. A three phase generator used this way will supply 58 percent of its three phase rating.

Balancing the load on either side of the neutral is very important, as it is easy to inadvertently overload one side of the generator. With perfect balance, there will be no current in the neutral, and the whole of the load will be carried at 230 volts. Single phase low voltage and high voltage transmission is discussed under the heading "Transmission" following.

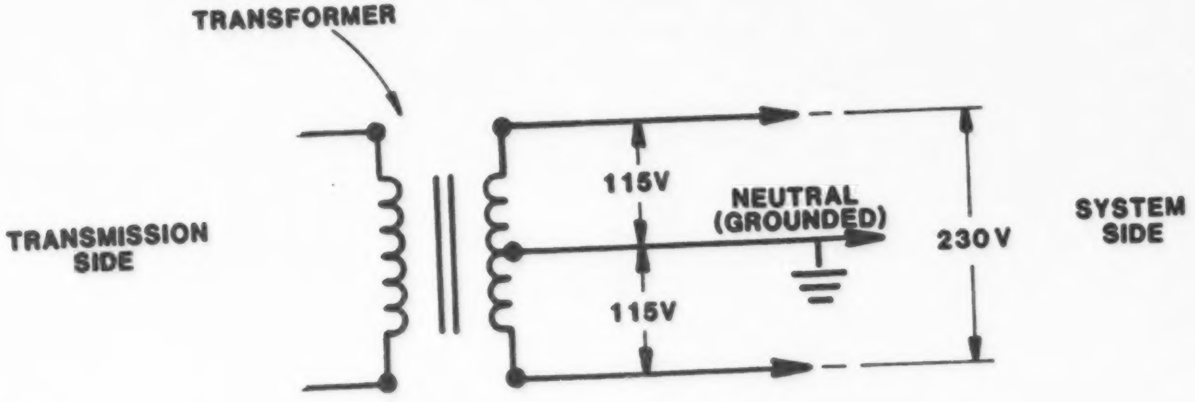
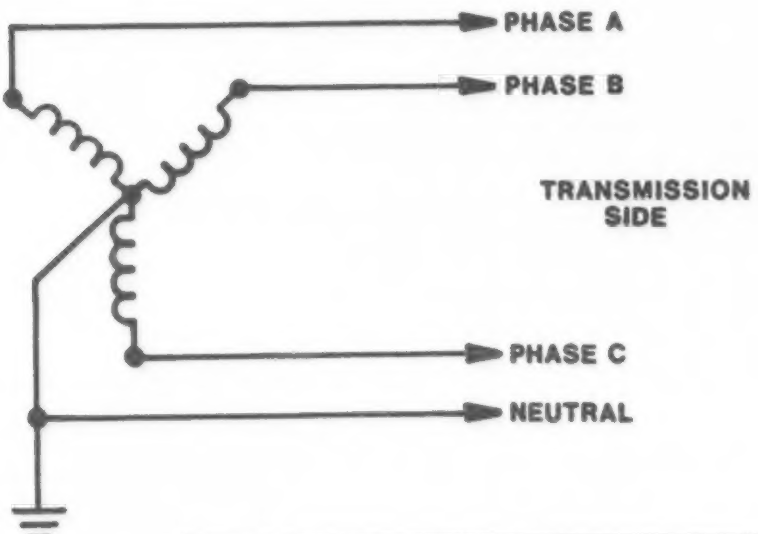

TRANSFORMER
TRANSMISSION SIDE
115V
NEUTRAL (GROUNDED)
115V
230V
SYSTEM SIDE

FIG.4-124 1-PHASE SYSTEM

Three Phase Systems

Three phase power is preferred over single phase, in all but the smallest systems, because three phase equipment makes much better use of expensive materials. Three phase generators are more compact and efficient than single phase generators, and motors are self-starting, robust and more reliable. All utilities and industrial operations utilize three phase power.


PHASE A
PHASE B
TRANSMISSION SIDE
PHASE C
NEUTRAL

A & B = 208V	A & NEUTRAL = 120V
B & C = "	B & " = "
A & C = "	C & " = "

FIG.4-125 3-PHASE STAR CONNECTION

In the above example, phase to phase voltage is 208 volts, and phase to neutral is 120 volts. This corresponds to the single phase system, with the exception that an additional wire is available for carrying the load. The ratio of voltages is different from single phase systems: 120 x 3 = 208 volts. The neutral is grounded as in the single phase system. Distribution panels and switchgear are similar to the single phase equivalent except for the addition of the third wire.

Three phase systems can be used to supply single phase loads by connecting them line to neutral. This is done for lighting and receptacles. Motors and larger loads are connected line to line as three phase 208 volt loads in order to keep the system balanced.

All phases must be balanced with fairly equal loads on each phase, otherwise one phase of the generator may become overloaded and burn out.

Three phase systems which feed industrial loads are sometimes connected in Delta, Figure 4-126.

Figure 4-127 and 4-128 illustrate basic single phase and three phase systems.

Three Phase Voltage - Current Relationships
(Refer to Figure 4-125) Star Connection

Volts per phase = 1.732 x phase to neutral volts = 1.732 x 120 = 208v
Amps per phase = amps per line

This system is used for local 120/208 volt 3-phase systems and for high voltage systems.

Delta Connection

Volts per phase = volts per line
Amps per phase = $\frac{\text{amps per line}}{1.732}$

The delta system is often used for high voltage transmission and occasionally on 600 volt systems, feeding motor and power loads having no requirement for a neutral.

Three phase generators, transformers and motors are always internally connected either in star or delta, but occasionally all leads are brought out for external connection as in 12-lead generators. Single phase transformers can be grouped into either star or delta connections.

Neutrals

For low voltage systems, either 120/240 volt single phase and 120/208 volt three phase, the neutral conductor must accompany the line conductors from source to load panels. On 460 volt or 600 volt

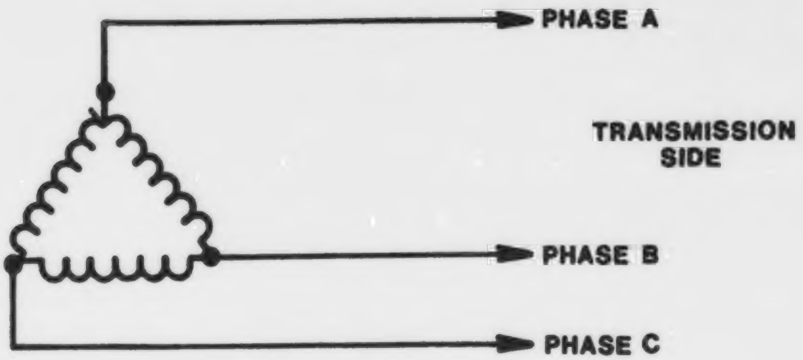

PHASE A
TRANSMISSION SIDE
PHASE B
PHASE C

FIG.4-126 3-PHASE DELTA CONNECTION

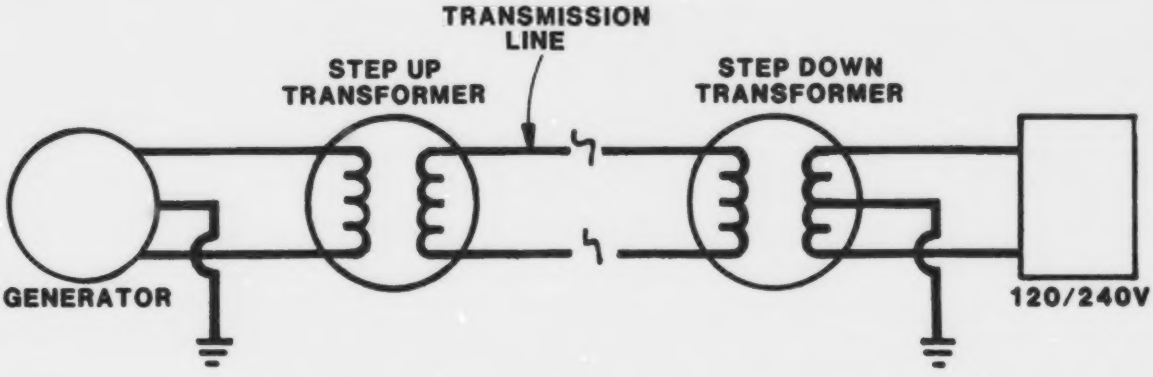

TRANSMISSION LINE
STEP UP TRANSFORMER
STEP DOWN TRANSFORMER
GENERATOR
120/240V

FIG.4-127 1-PHASE SYSTEM (BASIC)

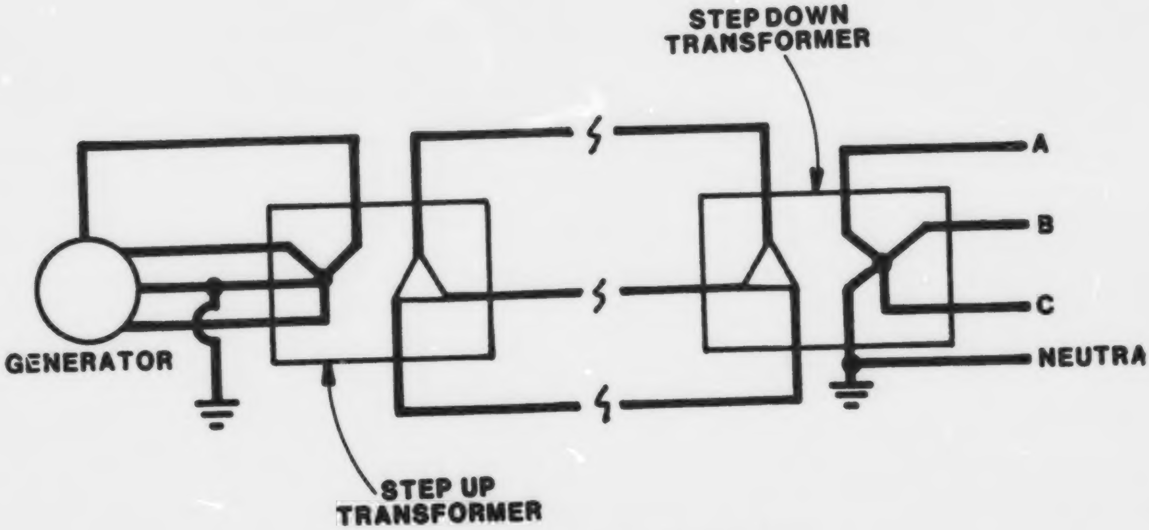

STEP DOWN TRANSFORMER
A
B
C
NEUTRA
GENERATOR
STEP UP TRANSFORMER

FIG.4-128 3-PHASE SYSTEM (BASIC)

system, installing the neutral is not necessary, since these voltages normally feed motors, etc. When stepped down to 120/208 volts for low voltage use, the neutral can be obtained from the transformer.

Neutral Grounding

In all cases, the neutrals must be grounded. Refer to the Canadian Electrical Code for cable sizes and methods.

4.30 AUTOMATIC EMERGENCY SHUTDOWN

Emergency shutdown is necessary in certain circumstances to avoid serious damage to mechanical or electrical equipment.

Emergency shutdown will be caused by two basic types of fault:

(a) mechanical or hydraulic failure; or
(b) electrical failure.

Mechanical failure may result in turbine runaway. This may be caused by governor failure; breakage or maladjustment of the governor linkage between the governor and turbine control elements; or jamming or breakages in the turbine jet deflector, spear valve, or Francis turbine wicket gate levers. A combination of poor adjustment and excessive wear in the turbine control mechanism can accumulate to eventually prevent complete shut-off of water, and in high head turbines, there may be sufficient water entering the turbine to cause runaway speed at no load.

Turbine runaway, on the mechanical level, may be detected by means of a rotating centrifugal switch driven from the turbine shaft. This type of switch, called a plugging switch or speed switch, is made to suit various speeds and can be adjusted through a moderate range. This switch can be made to close turbine, etc. valves by means of electric or hydraulic actuators.

An overspeed trip device is also available. This device is frequency actuated by overspeed and acts to trip the jet deflector, by means of a small hydraulic or air cylinder operated by an energy storage system device to initiate alarms.

When using an electronic load controller, overspeed will be detected by excessive frequency. When a "frequency guard" unit is installed, this unit will send an overspeed signal to the overshpeed trip device. Most such systems use either a compressed air or hydraulically actuated shut-down mechanism which can be triggered by the frequency guard unit.

In systems using energy storage such as a battery, compressed air or hydraulic reservoir, care must be taken to ensure that these items are maintained in good operating condition.

Plugging switches initiate shutdown by operating the turbine stop valve, while the overspeed trip device shuts the turbine down by deflecting the jet. Contacts can be provided on this device to cause the turbine and stop valve to close as well. Both types can be used to initiate alarms.

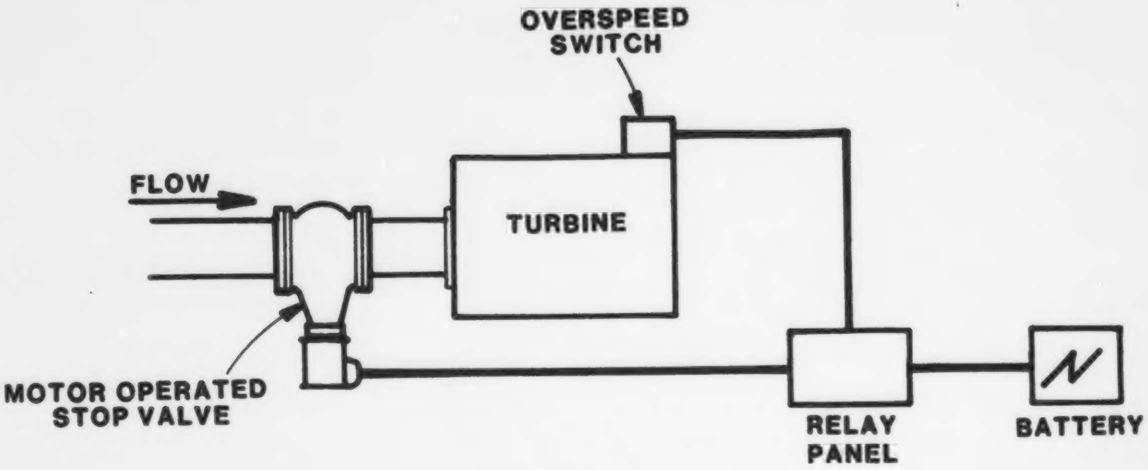

OVERSPEED SWITCH
FLOW
TURBINE
MOTOR OPERATED STOP VALVE
RELAY PANEL
BATTERY

FIG.4-129AN EMERGENCY SHUT-DOWN SYSTEM

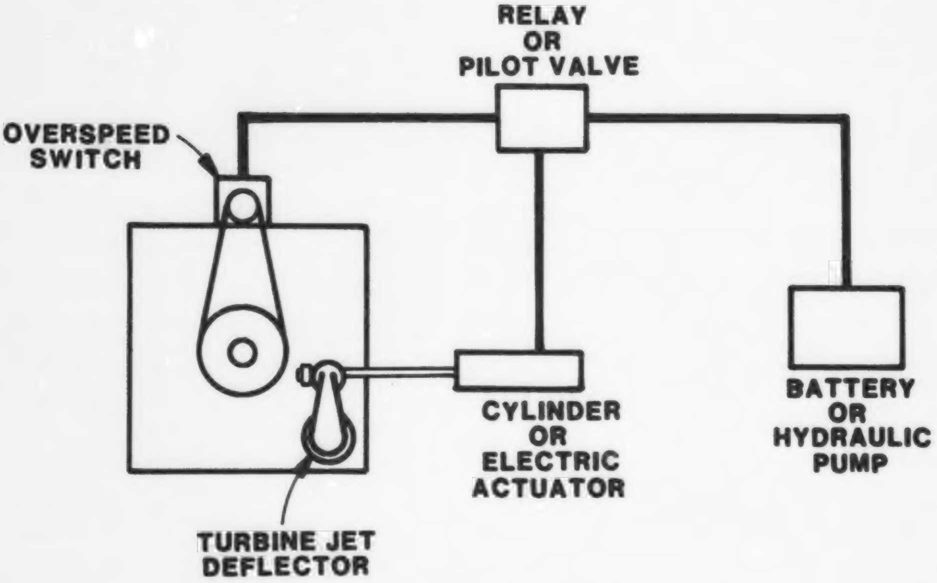

RELAY OR PILOT VALVE
OVERSPEED SWITCH
CYLINDER OR ELECTRIC ACTUATOR
BATTERY OR HYDRAULIC PUMP
TURBINE JET DEFLECTOR

FIG.4-130JET DEFLECTOR WITH ELEC.OR HYD.ACTUATOR

Hydraulic emergency shut-down devices can be home built using an automotive power steering pump, reservoir, and standard off the shelf parts such as a cylinder, and hydraulic solenoid valve.

Overspeed detectors should not rely on the governor as a means of shutting down the turbine, since governor failure is a prime source of overspeed. Most preventative systems make use of a motor operated turbine stop valve or hydraulic jet deflector actuators.

Overspeed devices must not be set too close to normal operating speed, to allow for transient speed variations caused by motor starting or switching of block loads. The usual range is 15 percent to 25 percent overspeed.

When turbines are equipped with overspeed devices, it may be tempting to use industrial grade generators. These are obtainable from a much larger range of manufacturers than are turbine overspeed rated units. However, all fail safe devices may be counted on to malfunction at some time, and therefore there is an element of risk involved with industrial grade generators. Most industrial generators are rated for 25 percent overspeed although at least one make is guaranteed to 50 percent (Caterpillar Americas Inc.). Sustained overspeed will wreck most industrial grade generators. Usually the rotor winding and sometimes the pole pieces come adrift causing irrepairable damage to the stator. The mechanical shock attendant on this type of failure can damage power transmission equipment and the turbine.

It is usually possible to install a back-up mechanical governor such as the pierce, which can be used to operate jet deflectors, gates, valves, or pilot devices. Most turbines (except pelter and Turgo) will not come up to operating speed on less than 20 to 30 per cent full flow. Hence, emergency overspeed devices such as butterfly valves need only be 3/4 closed to effect shutdown. This eases water hammer problems, since the flow is not suddenly and completely stopped. A combination of an electronic governor with back-up mechanical governor will significantly reduce the risk of destructive runaway when it becomes necessary to use a standard generator.

Although all turbine shutdown devices can be used to occasionally operate, directly on the turbine gates and valves, installing a separate, electrically operated valve in the penstock is usually more convenient. This avoids complications around the turbine and can be retrofitted, provided that water hammer considerations permit.

On larger, remote-controlled plants, vibration detectors are sometimes installed. These can be made to initiate turbine shutdown when vibration exceeds a set limit. Excessive vibration results from loose parts, and is an indicator of impending mechanical failure.

Bearing temperature sensors can be installed on either sleeve or ball bearings. Lube oil flow and pressure can also be monitored. Vibration and lube oil monitoring devices are usually two stage, providing an early warning visual and audible alarm for a set time period before initiating turbine shutdown.

Bearing temperature sensors are of dubious value on ball bearings. Failure is usually quite sudden, and routine inspection and maintenance is better insurance.

All high head impulse turbines should be protected by overspeed trip devices operating a turbine jet deflector. Other protective devices such as vibration and lube monitors should be considered on plants larger than 150 kW, and are more or less mandatory on plants over 500 kW. Much depends upon the characteristics of the plant. For instance, high head plants equipped with heavy flywheels tend to be more liable to bearing problems. Medium and low head plants should be protected against overspeed by electrical devices.

The most durable and practical type of turbine bearing is the spherical roller oil lubricated type, which should be specified wherever possible.

Electrical Failures

All generators should be provided with circuit breakers equipped with short circuit and overload elements, as this protection is required by the Canadian Electrical Code. The circuit breaker is the first line of defence for the generator.

Small hydro protective systems must incorporate over and under voltage and frequency relays, which disconnect the load from the generator when either voltage or frequency is outside normal limits. This feature is necessary to protect system loads such as motors, which may be damaged by voltage or frequency excursions. Motors are designed to operate satisfactorily only when the frequency is within plus or minus five per cent, and when voltage is within plus or minus ten per cent of rated value. Lighting, communications and computer equipment is voltage sensitive, and may be seriously damaged by voltages in excess of ten per cent above rated.

Sustained voltage and frequency excursions will cause generator breaker trip, but will normally not cause turbine shutdown. Both types of protection are furnished with adjustable time delay elements which act to prevent nuisance tripping in momentary fluctuations. Time delay depends upon anticipated value and duration of frequency and voltage variations, which in turn depend upon the recovery time after switching large loads or starting motors. Large motors on high inertia loads have acceleration times of up to seven or eight seconds, but ordinarily a three or four second time delay is sufficient for most plants.

High frequency is caused by the governor falling out of adjustment or by governor failure. Low frequency may be caused by governor troubles, but also may result from insufficient water. This may be a case of low flow, or the result of blockage in the intake, penstock, or turbine valves. High voltage may be caused by excessive speed, but both high and low voltage can be caused by voltage regulator or control circuit problems in the generator. Voltage and frequency protective circuits must be by-passed either manually or electrically during plant start-up.

Emergency failures can be made to operate a lock out relay which must be reset before the plant can be re-started.

Alarm Annunciator Panels

Pinpointing the cause of either mechanical or electrical failures is not always easy. Alarm annunciator panels are often installed for this reason, and depending upon the number of alarm points selected, will indicate the source of failure.

Alarm panels consist of a series of annunciators installed in a panel so that each alarm has a captioned window. The appropriate window lights up for each selected type of fault. An audible alarm is usually supplied. This type of equipment is not expensive, and should be considered.

4.31 REMOTE ALARMS

The alarm annunciator panel can be installed at a remote location. A sending unit is installed in the power plant together with a duplicate alarm annunciator panel, if desired. The connecting link is a telephone cable, either installed aerially or buried along the transmission line route. Such systems usually include a remote turbine stop pushbutton and an audible alarm. A variety of systems are available, some using a common wire with an additional wire for each alarm point, and others using pulse transmitters or tone control. Both are low voltage, low current applications similar to telephone circuits. A useful addition is a telephone connection between the power house and the remote alarm point using pairs in the same telephone cable.

Paralleled Generators

The presence of a diesel generator complicates matters. Additional alarm points are required to monitor the diesel engine. These include lube oil pressure and temperature, coolant temperature, fuel level, and cranking failure.

Faults associated with one generator may shutdown the entire plant. This is likely when one generator cannot accept the whole of the connected load at the time of the shutdown. This circumstance is difficult to guard against other than by automatic load shedding of non-priority loads. In cases where automatic load sharing equipment is installed, incorporating suitable protection into the control circuit may be possible. This problem is easier to remedy when electronic governing operating in conjunction with an energy sink, is installed.

Alarm Annunciator for Small Hydro Unit

Fig 4- Alarm Annunciator Panel Alarms

1. Main breaker trip)
2. Over/under voltage trip) always
3. Over/under frequency trip)
4. Turbine runaway trip)
5. Hot bearing)
6. Vibration) on larger plants

Notes:

(a) main breaker trip by itself indicates a short circuit or overload;
(b) alarm cancel turns off the horn but not the lights;
(c) the system is powered by battery and is independent;
(d) many other features can be added.

Remote Control

Small hydro plants can be arranged for remote start, stop, and emergency shut-down. The easiest and most useful control is a remote stop pushbutton. Fig. 4-138 illustrates a typical layout for full automatic control with remote control and annunciation.

Professional Assistance

The turbine-generator builder, or control panel manufacturer can advise on the necessary level of protection and control features. There is a number of small firms which can build control panels to suit any requirement, and can advise on installation and operation. On plants which are professionally designed, the protection and control features will be specified as a part of the work. However, control systems are a matter for liaison and discussion between the designer and user and this aspect should not be overlooked. As a rule, simpler is better.

4.32 D.C. SYSTEMS

Direct current is limited to very small systems, particularly when intermittent water flow necessitates the use of batteries to store energy. Voltage drop in low voltage systems requires the power plant and load to be in close proximity to one another.

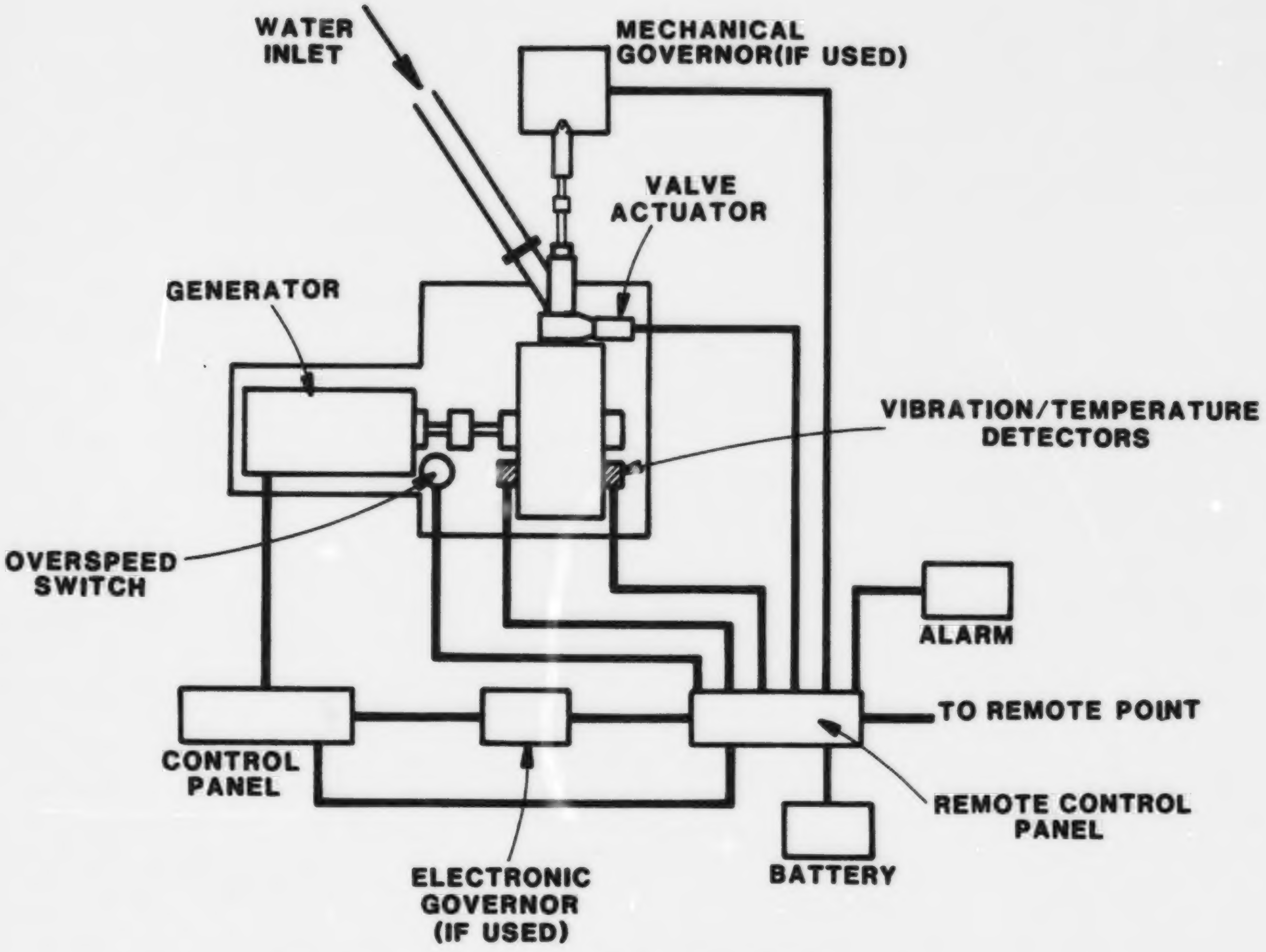

WATER INLET
MECHANICAL GOVERNOR(IF USED)
VALVE ACTUATOR
GENERATOR
VIBRATION/TEMPERATURE DETECTORS
OVERSPEED SWITCH
ALARM
TO REMOTE POINT
CONTROL PANEL
REMOTE CONTROL PANEL
ELECTRONIC GOVERNOR (IF USED)
BATTERY

FIG.4-131REMOTE CONTROL EQUIPMENT

Low Voltage Systems

110 volt systems are capable of supplying larger systems, over a few kilowatts, and are a workable alternative to A.C. systems in cases where energy storage is necessary. At one time 32 volt systems were in common use with rural windmill systems. Lamps are easy to acquire, but motors and appliances are harder to find. Try marine equipment sources. Actually, 32 volts d.c. is an inexpensive and adequate electrical system when transmission distance is short, and power demand is moderate: not over 1/2 kW average demand, with short duration peaks of less than 1 1/2 kW.

Twenty-four volts is commonly used in aircraft and on heavy construction equipment. Most aircraft generators are unsuitable for small hydro use. The rotational speed is anywhere from 2500 rpm to 6000 rpm and these generators are invariably airblast cooled. They are complicated and difficult to figure out, and are essentially highly stressed machines with short life expectancy. The best source of heavy 24 volt generators is the construction equipment market. Large 24 volt generators have been built by Delco Remy, Autolite, and Leece-Neville in sizes up to 100 amperes. The rotational speed was from 900 to 1800. These can usually be found as-is or rebuilt in equipment junk yards, or from auto-marine electrical shops.

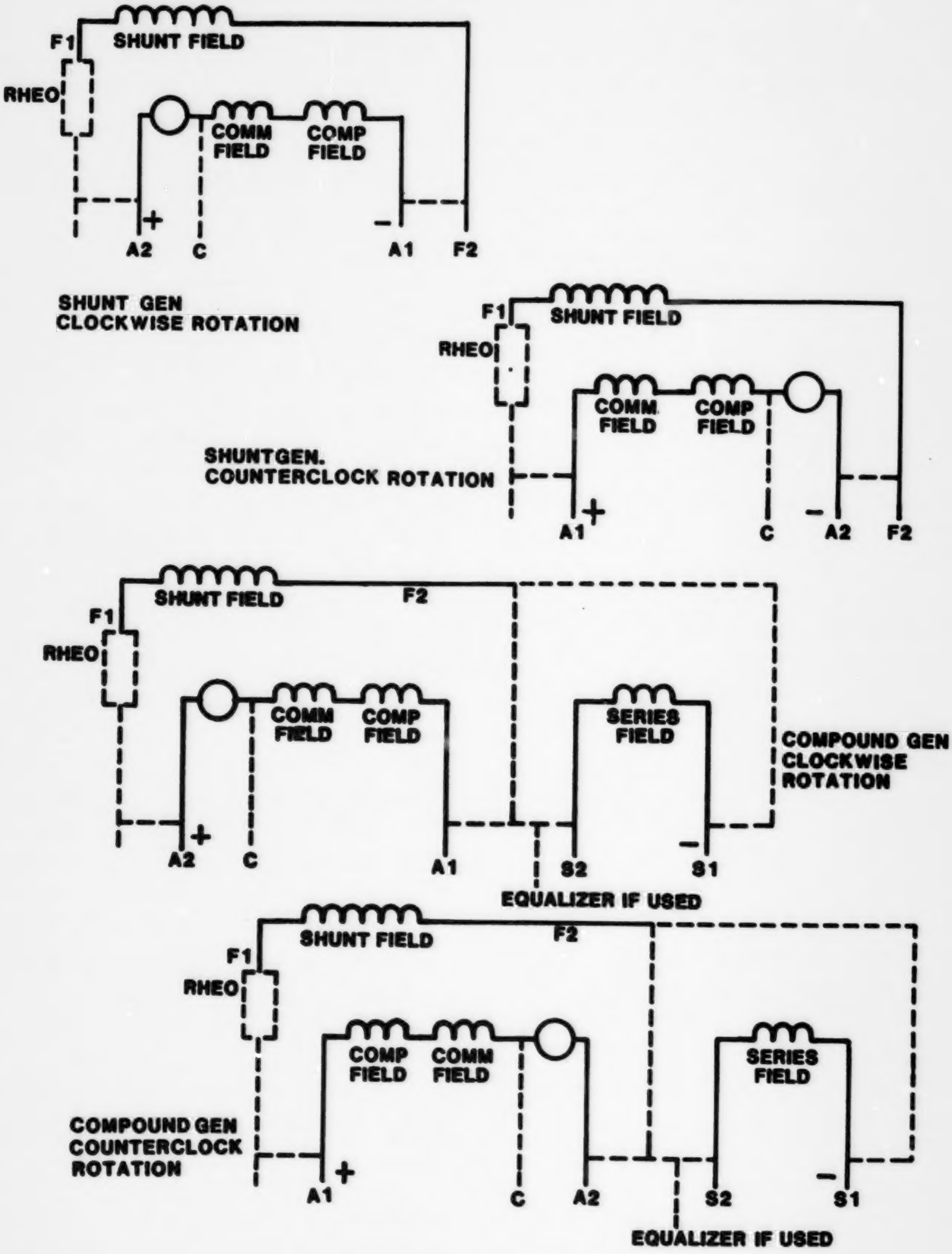
Twelve volts equipment is extensively used in recreational vehicles, and a wide range of appliances and electric tools are available. Twelve volt alternators and generators are easy to obtain either from auto-marine electrical firms, or from scrap yards. Automobile alternators can be used, connected to batteries. They must usually be driven above 2500 rpm, which could pose mechanical problems.

Batteries are necessary on D.C. systems only when storage of energy is necessary. When planning a D.C. system, the voltage should be higher than the full load current. For example, a 32-volt, 22-amp system would be superior to a 12-volt, 60-amp system even though the wattage is the same. The battery is usually sized to supply about one-half of the full load of the generator, and to carry this half of the load for 10 hours to 15 hours on one charge. The initial charge rate of the generator should not exceed about two thirds of the generator rating, to permit one third total output to be supplied to the load. Battery suppliers will recommend the correct type and size of battery to use, but for D.C. systems a deep cycle battery will give best results.

4.33 ELECTRICAL INSPECTION AND CODES

The inspection of all electrical installations is required by statute law. Responsibility for conducting electrical inspection devolves upon the Provincial electrical inspectors, who operate out of the Safety Engineering Services Division, Ministry of Labor. The head office in Vancouver is responsible for administrating municipal and regional branches throughout the Province of British Columbia.

The inspectors regard their role as primarily an educative one, and do not withhold final approval except under unusual circumstances. Reasons for non-approval may include sub-standard or poor quality work, hazardous installations, or refusal on the part of the owner to carry out remedial work. Most electrical inspectors are a valuable source of information and assistance, and should not be viewed as adversaries or obstacles to progress.



SHUNT GEN
CLOCKWISE ROTATION

SHUNTGEN.
COUNTERCLOCK ROTATION

COMPOUND GEN
CLOCKWISE
ROTATION

COMPOUND GEN
COUNTERCLOCK
ROTATION

F1
SHUNT FIELD
RHEO
COMM FIELD
COMP FIELD
+
−
A2
C
A1
F2
F1
SHUNT FIELD
RHEO
COMM FIELD
COMP FIELD
+
−
A1
C
A2
F2
SHUNT FIELD
F2
F1
RHEO
COMM FIELD
COMP FIELD
SERIES FIELD
+
−
A2
C
A1
S2
S1
EQUALIZER IF USED
SHUNT FIELD
F2
F1
RHEO
COMP FIELD
COMM FIELD
SERIES FIELD
+
−
A1
C
A2
S2
S1
EQUALIZER IF USED

FIG.4-132DC GENERATOR CONNECTIONS

The Canadian Electrical Code C22.2, Part 1

This set of electrical standards is published by the Canadian Standards Association. CSA is a private organization, and as such has no legal powers to enforce its regulations. However, since electrical standards are necessary, the Canadian Electrical Code has been authorized for use throughout Canada. The final authority in electrical standards remains with the Provincial inspectors. Certain code standards have been accepted with various reservations, all of which are covered by supplementary bulletins and amendments published by the Electrical Safety Branch. "The Electrical Code Simplified", covers the main points to watch, and has the tacit approval of the provincial inspector.

The Canadian Electrical Code is not intended as an instruction manual. All of its rules and regulations must be interpreted in the light of training and experience in electrical installation work. There are in addition, many books on electrical installation. Many do-it-yourself electrical books illustrate methods which do not comply with local electrical codes and some even contain errors.

The Permit Process

Prior to starting work on any electrical work beyond simple household additions, you are required to take out an electrical permit. There are two forms, one intended for private individuals, and one for contractors. Both are obtainable from the local electrical inspection department. Provided you can sensibly complete this form, which requires a minor technical description of your installation, you are unlikely to be refused a permit. You should obtain a form prior to making an official application, so you can piece together the necessary facts. Where contractors or licenced electricians are employed, they will take out the permit.

You will normally require a Class B electrician for power house work and private power line construction, and a Class A electrician for commercial systems involving overhead lines on public property.

What You Can Do

You may undertake electrical work on your own property for your own use: you have this right in law. However, you are required to take out a permit, and you may not put your system into operation, other than for test purposes, until it has been approved by the local provincial or municipal electrical inspector. When your system has received final approval, you will be issued an approval certificate.

Certain provincial inspectors may wish to satisfy themselves as to your proficiency. Therefore, you might wish to do some previous study, and be sure that you can adequately describe in detail what you intend to do. A drawing is of great assistance here. For work involving voltages greater than 750 volts, or services larger than 400 amperes, a drawing is required by the provincial inspector.

Drawings for installations of this size are normally done by contractors or engineering firms.

What Electricians Can Do

Class A and Class B electricians, who are familiar with the Electrical Code, are competent to draw up electrical plans and work out the technical details. However, they are not necessarily adept at forward planning or overall concepts, fields which are best left to consultants or engineers.

Most electricians are specialized: those who have specialized in industrial work will likely be familiar with generators and high voltage construction, while those who normally work in residential or commercial premises may not be experienced on power system work. You should ensure that the electrician you plan to hire has the right kind of experience.

Electricians do not like to clean up sloppy work so that it can get past the inspector. The work must be meticulous, so take sufficient time to do the work properly. Electricians and your electrical inspector are sources of information, and, electrical wholesalers can often advise you and assemble the necessary items for your job. Rather than purchasing a large quantity of parts and equipment at one time, work the job out in distinct assemblies, purchasing these as units as the job progresses.

What You Must Not Do

Do not ignore the electrical permit and inspection service. Sooner or later an inspector will arrive on your doorstep, and you may be required to shut your system down for expensive alterations. Electrical inspectors are well versed in electrical safety requirements, and they may identify hazards you neither see nor understand.

Limits

Do not attempt to perform major electrical construction without experienced help. Arbitrarily, this includes generators over 50 kW, voltages above 240 volts, or high voltage installations. Additionally, you will probably need assistance for the work on control systems, which normally involve careful circuit checking before and after energizing. Sometimes you can arrange with an electrician for you to do the donkey work while he does the planning, connections, and testing. If your installation is intended for commercial purposes, or constitutes a part of the assets of a business or company, you are required by law to employ a certified electrician in a supervisory capacity.

Worker's Compensation

Anyone you employ on your project must be covered by Worker's Compensation, but as owner and employer, you do not require coverage. Worker's Compensation has a range of electrical standards which deal mainly with safe working practices on electrical equipment.

Safety Considerations

Electric Shock Hazard

Electric shock from voltages above 50 volts are potentially life threatening.

Electrical shock has several sources:

(a) working on live equipment;
(b) using defective equipment with exposed live parts;
(c) equipment enclosures which have become energized through internal fault;
(d) inadequate or non-existent grounding connections.

Electrical Arcs

Electrical arcs if not properly interrupted and confined, create enormous volumes of ionized hot gases, often containing particles of molten metal. Unrestrained arcs can blow up equipment, throw molten metal, blow doors off switchgear, etc. The hazards of third degree burns, clothing fires, and permanent disability are considerable. Arcs can cause flash burns to the eyes. Burns can be inflicted by overloaded equipment, and this is responsible for a sizeable number of injuries.

Human Factors

The cure for any and all of the above items is obvious, and to list them is not to predict that accidents are bound to occur. However, steps should be taken to make sure that accidents waiting to happen are avoided as far as possible. Here is a list of steps which must be taken (it is exhaustive: there may be more).

1. Familiarization

   (a) Read and understand brochures and manuals.

   (b) Examine all equipment inside and out whilst studying the manual. The best time to do this is when the equipment is being installed.

   (c) Ask a lot of questions.

   (d) Make trial runs on maintenance and test procedures.

2. Understanding

    (a) Take a course in basic electricity.

    (b) Read books on maintenance and servicing.

    (c) Get to know individuals who have hydro plants of their own, or are responsible for maintaining electrical machinery.

    (d) Read publications on electrical safety.

    (e) Familiarize children with the power plant and educate them on what they must not touch. Children are especially vulnerable to accidents because of their natural curiosity.

    (f) Resist the impluse to fiddle. As with cars, power plants operate better when left alone.

    (g) Borrow movies which are available on loan from B.C. Hydro, and which cover various aspects of operation and safety.

3. Housekeeping

    (a) Keep the floor free of tools or other objects and clean up oil and water spills as they occur.

    (b) Paint the floor with non-slip paint.

    (c) Make sure that machine guards are secure.

    (d) Do not use the powerhouse for a store room especially for inflammable materials.

    (e) Keep the powerhouse locked.

    (f) Maintain adequate lighting.

    (g) Keep a file for maintenance manuals, drawings, etc. in the power plant.

    (h) Keep a dedicated tool kit in the power plant.

    (i) Keep spares and lubricants in stock and labelled.

    (j) If possible, install an extension telephone in the power plant.

    (k) Keep a good emergency lantern in the power plant. An especially effective type is a propane lantern which can be suspended from the ceiling.

    (l) Keep a propane or kerosene heater in the power plant. This will be convenient in winter, and should be kept going when the plant is shut down for lengthy periods.

4. Work on Equipment

(a) Do not work on live electrical equipment. As an exception, sometimes protective equipment, governors etc. must be adjusted or tested when energized. When this is necessary, do not work alone.

(b) When working on downstream circuits, be sure that disconnects are padlocked in the open position. On circuit breaker panels, tie a warning tag on the handle.

(c) Never pull disconnect switches which are carrying heavy currents. Reduce the load first. They are a safety feature and are not designed to switch loads.

(d) Whenever repairs are required on the turbine or generator, be certain that valves are shut and cannot be inadvertently opened. Figure out a way of chaining and padlocking them. Wire an on-off switch into the circuit-feeding, motor- operated valves to prevent accidental electrical operation.

(e) Shut down and padlock the plant when working on transmission lines as well. Otherwise, someone may start the plant up while you are 25 feet up a pole, hanging on to the transformer.

(f) Beware of backfeeds in electrical wiring, especially on control circuits which commonly interconnect several pieces of equipment, and often run between panel sections.

(g) Do not work on equipment if you are ill, hung over, or in an exceedingly bad temper. Get help.

(h) See section on mechanical power transmission following for maintenance considerations and safety features.

(i) If in doubt, shut the plant down.

Finally, convenience and independence have their price, and demands upon time, care, and attention must be met. In most instances the plant can be shut down for minor repairs and adjustments without serious inconvenience, and this is the preferred course of action.

4.34 POWERHOUSE DESIGN

There are several important considerations which enter into design of the powerhouse. The function of the powerhouse is to provide a stable platform for the machinery, and to offer a protective enclosure against weather. This must be achieved at minimum cost, using good building practices.

The foundations will be structural concrete, with adequate provisions for the machinery and superstructure weight. Resistance to hydraulic forces, local conditions of frost, and the type of soil on which it must be built, must also be considered.

Many types of construction are possible, and you should use the type most suitable for your needs and budget. Headroom is always a consideration, especially if you are installing chain block lifting gear. The details of construction are governed to some extent by local building codes and individual preferences. Unless you are well versed in building practice, you should study books on concrete masonry, concrete block, and timber and steel framing practices. Become familiar with the local building regulations, although these are not usually very exacting for industrial buildings.

The basic necessities with respect to powerhouse construction are:

(a) size estimates and interior layout;
(b) foundations;
(c) choice of building materials;
(d) ventilation and heating;
(e) building services;
(f) fire prevention.

Size and Interior Layout

Interior space is dictated by the size of the machinery and equipment, working space, and access requirements. When purchasing a new turbine-generator, a preliminary drawing can be obtained from the builder. At some later date, the turbine builder will forward final drawings and a layout showing the location and size of the discharge chute and bolt centres. These details can then be added to the powerhouse drawing. Construction should not begin until all details are known, and an accurate drawing made. For preliminary estimating purposes, obtain from various turbine builders, sketches showing the overall dimensions. Use these sketches to arrive at a reasonably close estimate for quantities and costs.

There are two basic types of powerhouse, those intended for impulse turbines, and those intended for Francis or other types of turbines which require a draft tube. Suggested layouts are provided for each, together with a number of sketches illustrating variations.

Plan for Impulse Turbine Powerhouse (Fig 4-133)

The main features are:

(a) plinth six inches high supporting the turbine generator;
(b) at least three feet clearance around the equipment, four feet clear in front of the switchgear;
(c) door wide enough to admit the equipment;
(d) man door opening outward;
(e) a cupboard for storing spaces and documents;
(f) six inch plinth under switchgear;
(g) no trenches or obstructions on or in the floor;
(h) good working access around turbine stop valve and governor;
(i) unit steel base supporting turbine-generator;

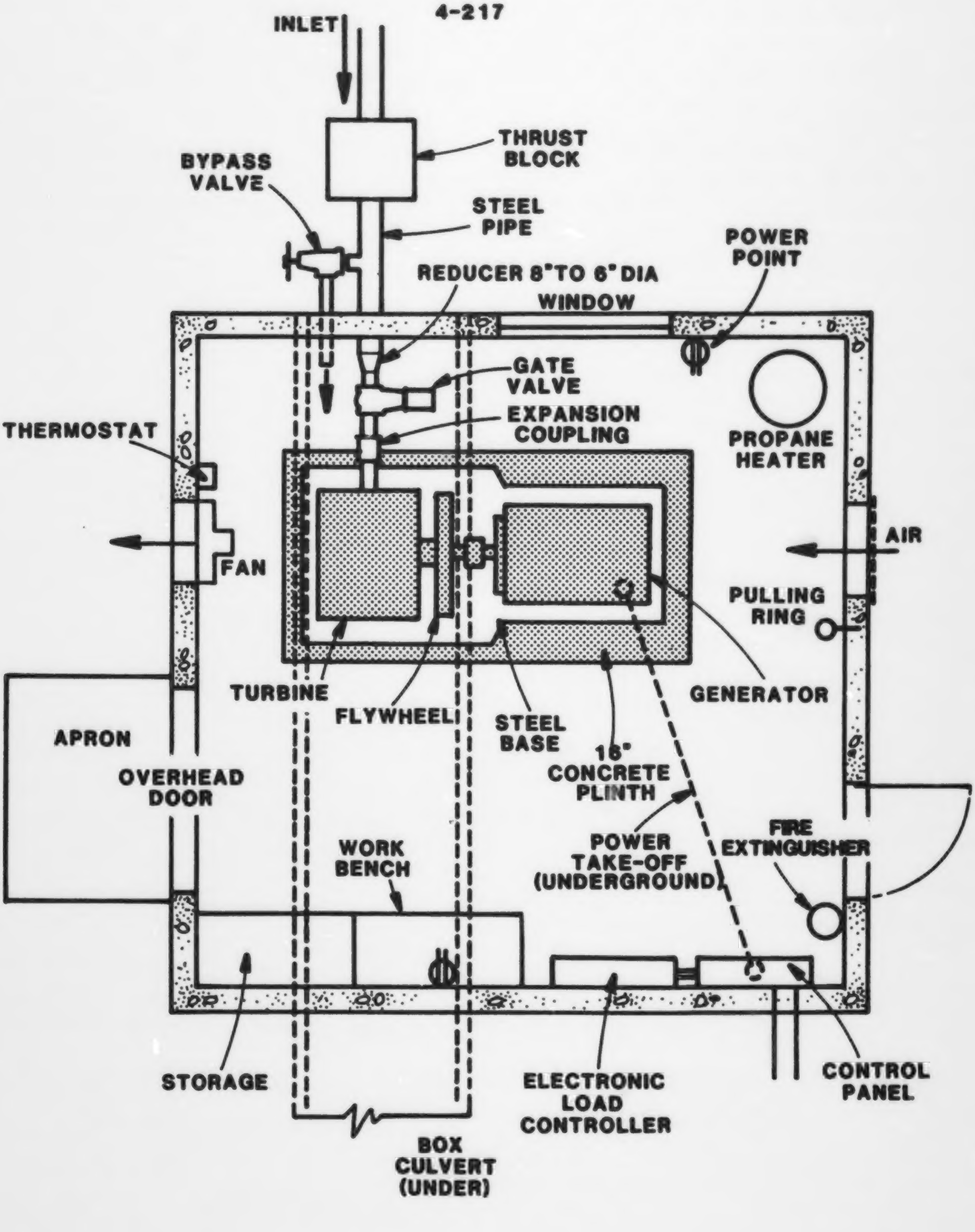

INLET
THRUST BLOCK
BYPASS VALVE
STEEL PIPE
POWER POINT
REDUCER 8" TO 6" DIA
WINDOW
GATE VALVE
EXPANSION COUPLING
PROPANE HEATER
THERMOSTAT
FAN
AIR
PULLING RING
TURBINE
FLYWHEEL
STEEL BASE
16" CONCRETE PLINTH
GENERATOR
APRON
OVERHEAD DOOR
WORK BENCH
POWER TAKE-OFF (UNDERGROUND)
FIRE EXTINGUISHER
STORAGE
ELECTRONIC LOAD CONTROLLER
CONTROL PANEL
BOX CULVERT (UNDER)

FIG.4-133PELTON TURBINE POWERHOUSE

(j) one or more windows;
(k) pulling ring in the floor for winching in equipment with come-along;
(l) concrete apron for unloading and jacking equipment into rollers;
(m) fire extinguisher, rated for use on electrical fires;
(n) adequate lighting and receptacles;
(o) louvres or louvre and extractor fan, depending on size of generator;
(p) overhead cable connection between generator and switchboard;
(q) kerosene or gas heater for use in winter during plant shutdown;
(r) ground bus.

For up to 50 kW, this power plant works out to about 14 feet x 14 feet inside. The size for a belt driven generator would be about the same. Twin jet turbines often require extra space behind the turbines. For up to 100 kW, approximate size becomes 16 feet x 16 feet.

The discharge chute is made sufficiently large to carry the turbine discharge at full load without exceeding two feet per second. A slope of 1/2" in 10 feet may be used.

Height of the floor should be some distance above the maximum height of the tailwater at maximum flood conditions. At least two feet to three feet should be allowed, to cope with unusual conditions, such as icing, dams and floods.

Powerhouses for Turbines with Draft Tubes (Fig 4.134)

Turbines such as the Francis, Crossflow, propeller, and Kaplan use draft tubes to induce a suction head on the turbine discharge. This feature enables the head between the intake and tailwater to be maximized. This type of installation requires what is in effect a two-storey structure, which is very similar in appearance to a pumphouse. The powerhouse floor slab is self-supporting and must be stressed to withstand the weight of the machinery, torque reaction and hydraulic forces. This type of machinery is commonly larger and heavier than machines for impulse turbines. As a result of the foregoing, larger draft tube powerhouses should be professionally designed.

Turbine Setting

Turbine setting is the dimension between the turbine centreline (usually) and the tailwater level. The length varies according to geographic elevation. The bottom of the tube must be submerged. Setting is a complex calculation involving trade-offs between turbine efficiency, tailwater level, and cavitation. See sections on Draft Tube and Tailwater.

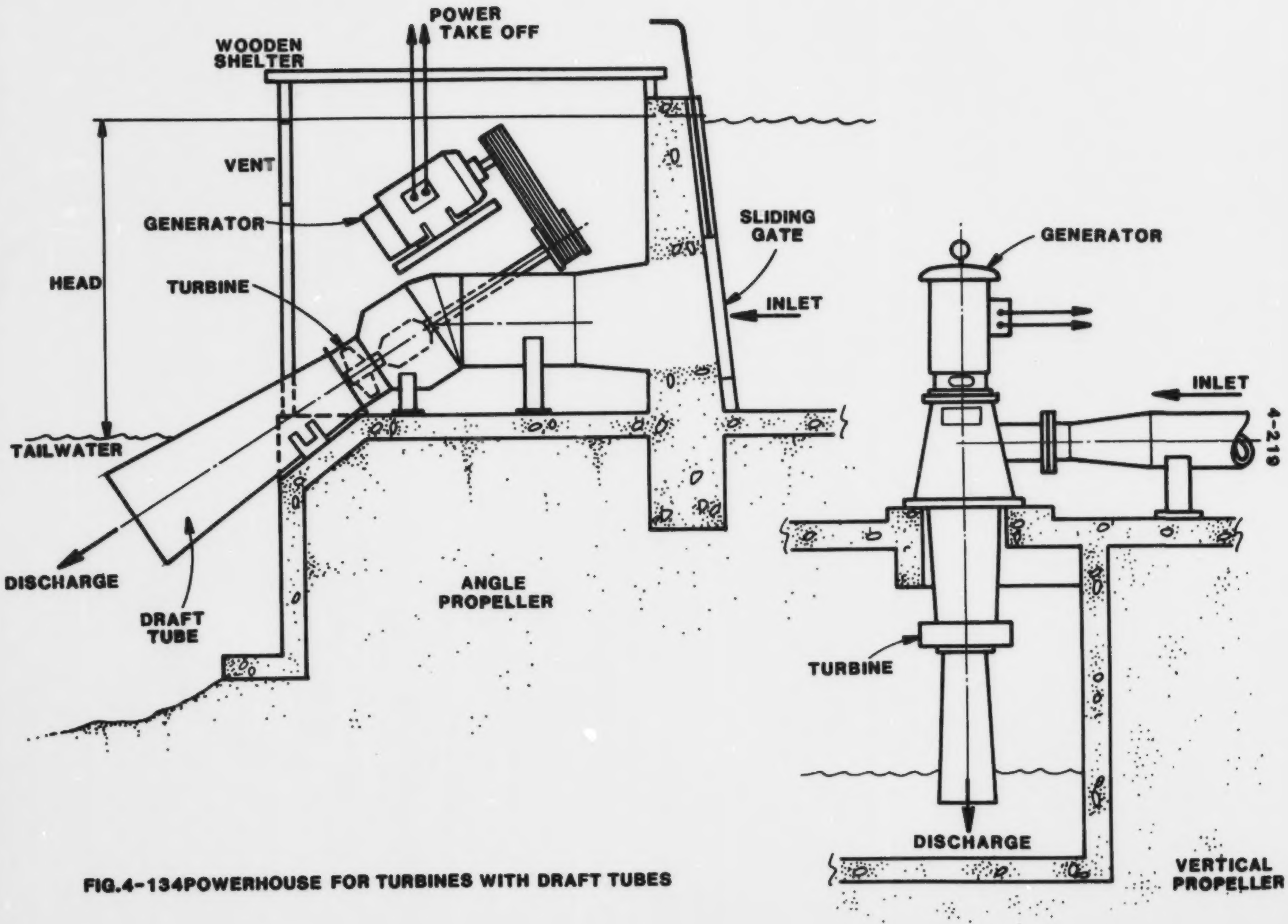

POWER TAKE OFF
WOODEN SHELTER
VENT
GENERATOR
HEAD
TURBINE
SLIDING GATE
INLET
TAILWATER
DISCHARGE
DRAFT TUBE
ANGLE PROPELLER
GENERATOR
INLET
TURBINE
DISCHARGE
VERTICAL PROPELLER

FIG.4-134POWERHOUSE FOR TURBINES WITH DRAFT TUBES

Foundations For Impulse Turbine Powerhouse

Basic construction normally consists of a perimeter wall and footing carried down to below the local frost line. The turbine-generator unit can be installed as a box culvert which should be poured on undisturbed earth. Reinforce using 6x6x6 weld mesh all around or by means of stirrups and longtitudinal reinforcing bars on 12" centres. The discharge chute must be incorporated into this block. The floor slab can be poured as an infill between the box culvert and the walls, installing an expansion joint around both. The floor slab may be four inches thick for machines up to 2000 pounds, but over that, six inches should be used. All concrete must be placed on fully compacted granular fill or upon rock. All concrete must be reinforced. The perimeter walls should have at least two continuous No. 4 bars around the footing and around the top to prevent temperature cracking. The equipment block and floors should be reinforced using No. 4 bars on 12 x 12 centres. Floor slab bars should be placed about a third up from the bottom. A useful alternative is welded reinforced mesh.

The machinery holding down bolts may be cast into the base. These should be hooked, and set well down into the base. A good plan is to weld the bolts into an angle iron or rebar frame which can be cast into the base. Turbine builders will supply these, which can be shipped loose in advance of the turbine. Bolts should follow the turbine builder's recommendations. Self-drilling concrete bolts can be used for smaller equipment.

Foundation For Reaction Turbines

The foundation for reaction turbines may be generally as above, with some exceptions. Because of the increased height of the foundations, more reinforcing is necessary, and the walls themselves may have to be thicker. The equipment floor slab is not supported on grade, and must be stressed for the weight of the machinery plus the weight of water in the turbine. Structural consideration should be given to the generator torque and possible shock loads. In general, reaction turbine structures or those involving columns, beams and monolithic structures must be designed by structural engineers.

Floor Drains

The floor should be sloped or gullied towards a floor drain fitting. For convenience, this can be sloped towards the rear corner by the turbine stop valve. This avoids the installation of conduits and stub-ups which are always in the way and prone to damage.

Foundation Drainage

Groundwater can cause uplift on flat concrete slabs, which can lead to cracking, leakage, and building movement. To prevent trouble from this source, the interior fill must be drained by means of 2" plastic pipes cast into the walls. Perimeter drains (foundation drains) must also be installed, and should be drained to a low point such as the creek.

Heating

Heating should be considered during lengthy shutdowns in winter or wet weather. Electrical machinery and equipment should be kept warm and dry at all times. A small propane or kerosene heater is adequate since the interior needs to be only a few degrees warmer than outside temperature.

Ventilation

The generator is cooled by an internal forced draft fan, and the inlet temperature must not exceed 40°C. Recirculation of air within a closed building will lead to overheating. Ideally, cool clean air is drawn into the generator, discharged from the front of the generator, circulated around the switchgear and other equipment, and finally discharged through louvres at roof level. The cool air intake should be at floor level near the air intake end of the generator, while the outlet should be placed in the opposite wall as high up as practical, above the turbine. Openings such as galvanized expanded metal are acceptable, but slat louvres are better. These should be the manually adjustable type rather than the self-actuated type which tend to seize up.

The size of opening is proportional to the size of the generator. Normal heat losses into the building surfaces are sufficient to cool very small units up to about six kW, but ventilation openings should be installed for larger units.

Larger sizes require a thermostatically controlled fan in the outlet opening. Rather than go into extensive calculations, the following tables have been worked out:

Gen.size (kW)	Losses,(kW)	Inlet Opening	Fan Size
15-30	3	2' x 2'	1/50 HP
30-75	7.5		
75-125	12.5	3' x 3'	1/10 HP
125-175	17.5		
175-250	25	4' x 4'	1/4 HP

The thermostat should be set for 65°F. Since the turbine is colder than any other object in the powerhouse, condensation usually forms on it especially during hot weather. Placing the extract fan above the turbine helps to draw off moist air.

Building Services

Install adequate lighting: using twin 40 watt fluorescent fixtures, install one for each 60 square feet of floor area. These should be on the ceiling or at least eight feet off the floor. Install one or two receptacles supplied from ground fault circuit breakers. These should be at waist height. Install a rechargeable battery lantern on a shelf beside the door. This should have its own charger and receptacle. If batteries are required for any reason, install a small sink and water faucet. Install an outdoor lighting fixture above the access door. Provide an electrical fire rated extinguisher and install this just inside the door. Provide a small propane or kerosene heater for use during winter maintenance or lengthy shutdowns.

Fire Prevention

Fires may be caused by electrical faults, overheating of equipment, or accidents with propane or kerosene heaters. Electrical fires are quite rare in properly installed modern electrical equipment. An important point of electrical safety is to install adequately rated cables, circuit breakers and wiring. All installation work must be thoroughly performed, in a manner which does not cause damage to insulation or equipment. Terminals and connections must be made using approved techniques. Overloading must be avoided, and protective equipment must be provided to guard against short circuits and overloads. Careful design and installation will reduce the probability of electrical fires to a very small level. Propane or kerosene heaters should be purchased new, and used only in the powerhouse. In use, place heaters where they cannot be accidentally knocked over. Do not store inflammable liquids or other materials in the powerhouse. Keep oily rags in a metal bucket, and do not accumulate large quantities. In locations where forest fires are a hazard, remove trees within falling distance of the power plant, and remove brush and other vegetation which could propagate a ground fire. Install a sheet metal roof. Install a two inch valve and hose connection on the penstock outside the powerhouse.

When installing electrical panels in a wood framed building, install fine rated Gyprock or other material between the switchgear and mounting surface.

Fire Rating

Local building codes may ask for one hour fire rating in powerhouse buildings which are adjacent to, or a part of, normally occupied buildings. This rating usually consists of a double layer of fire rated 5/8 inch gyproc.

Installation of Equipment

Installation of machinery is covered in the section, Mechanical Power Transmission.

Additional Considerations

Penstocks should not be bonded into the building walls. Bring penstocks in through a slot, and when finally installed, grout in the void space around the penstock after first wrapping the pipe with six or eight layers of heavy plastic sheeting. This will permit a small degree of movement during operation. The turbine stop valve will normally be carried on a flange welded to the end of the penstock, with a flexible coupling between it and the turbine inlet. Some arrangement must be provided for convenient removal of the turbine inlet pipes in order to clean out debris. Depending upon the design, pipes can sometimes be easily removed. Otherwise install a 12 inch spool in the turbine side of the stop valve.

Moving Equipment

Moving equipment is usually possible using planks and pipe rollers, which should bring the equipment above the level of the hold-down bolts. When in position the equipment can be lowered by means of jacks, wedges, etc. For removing turbine or generator parts for cleaning or inspection, an overhead beam and chain block is very useful, if funds allow. Otherwise, a lot can be accomplished using an automobile engine removing crane, which will lift about 700 pounds or more, and can usually be rented. Electrical control panels are often small enough to be bolted to the walls at convenient working levels. They should be located adjacent to the access door and away from the turbine.

Figure 4-134 to 4-139 illustrate a variety of powerhouse layouts.

Figure 4-140 and 4-142 illustrate foundation details.

Figure 4-143 to Figure 4-146 give dimensions for estimating different typical powerhouse source requirements.

4.35 TECHNICAL REQUIREMENTS FOR GRID CONNECTED PLANTS

Each utility company will have differing requirements for grid connections, however all will demand adequate electrical protection, control and metering. Safety is paramount; a principal function of the protective system is to prevent feeding energy into a utility line which has either been switched out for maintenance, or tripped out on a utility system fault. Small hydro plants can feed sufficient power into a utility line to constitute a hazard to personnel, and can contribute to persistent faults.

Utilities are less concerned about actual protection of the small hydro generator, which can be damaged by utility operations under certain circumstances. For instance, the utilities commonly use high speed reclosing on rural lines. These lines are automatically switched on, or reclosed, in response to temporary faults, and reclosing can occur more than once, as for example, tripping and reclosing in response to conductors touching in a windstorm. Reclosing operation could re-establish the line voltages out of phase with the hydro generator, and the resulting currents could cause damage to the generator. This problem is difficult to solve

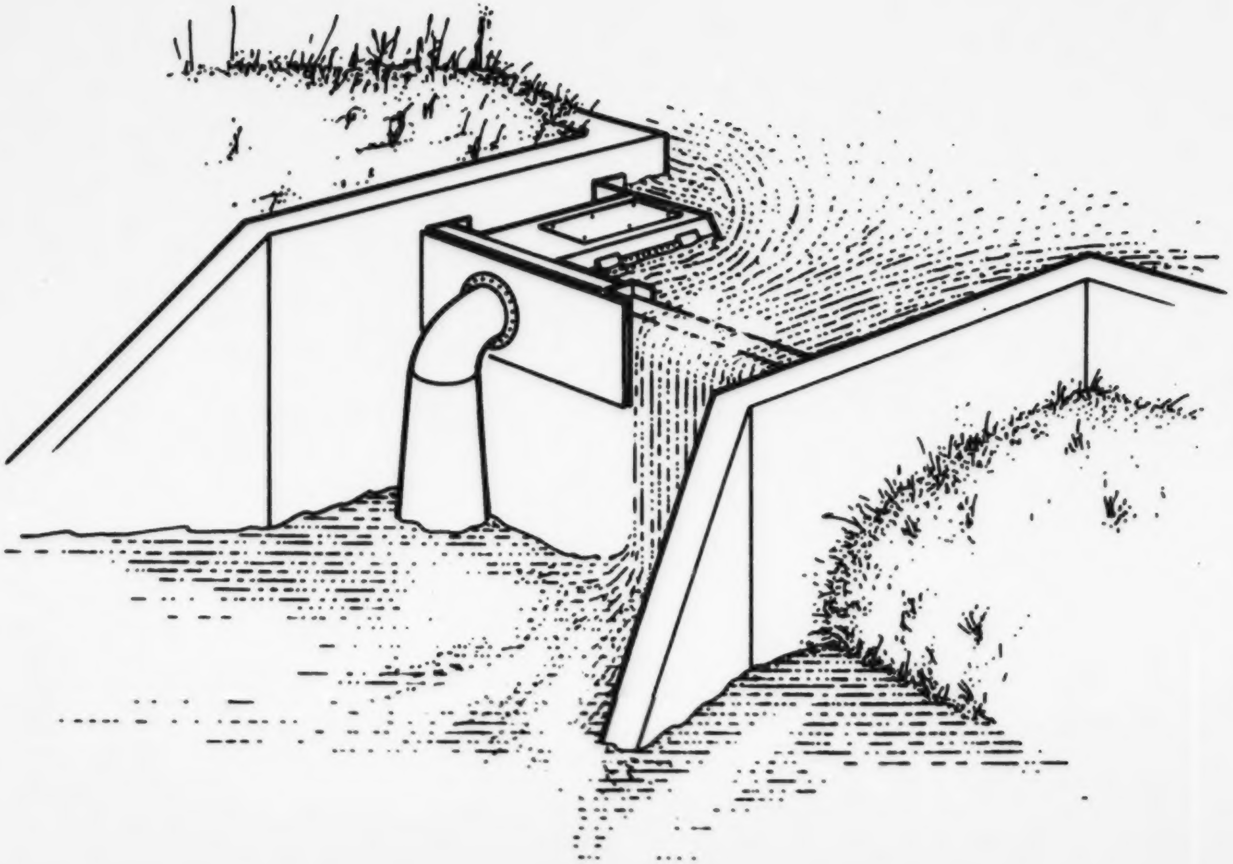


FIG.4-135LOW HEAD UNIT (GALT)

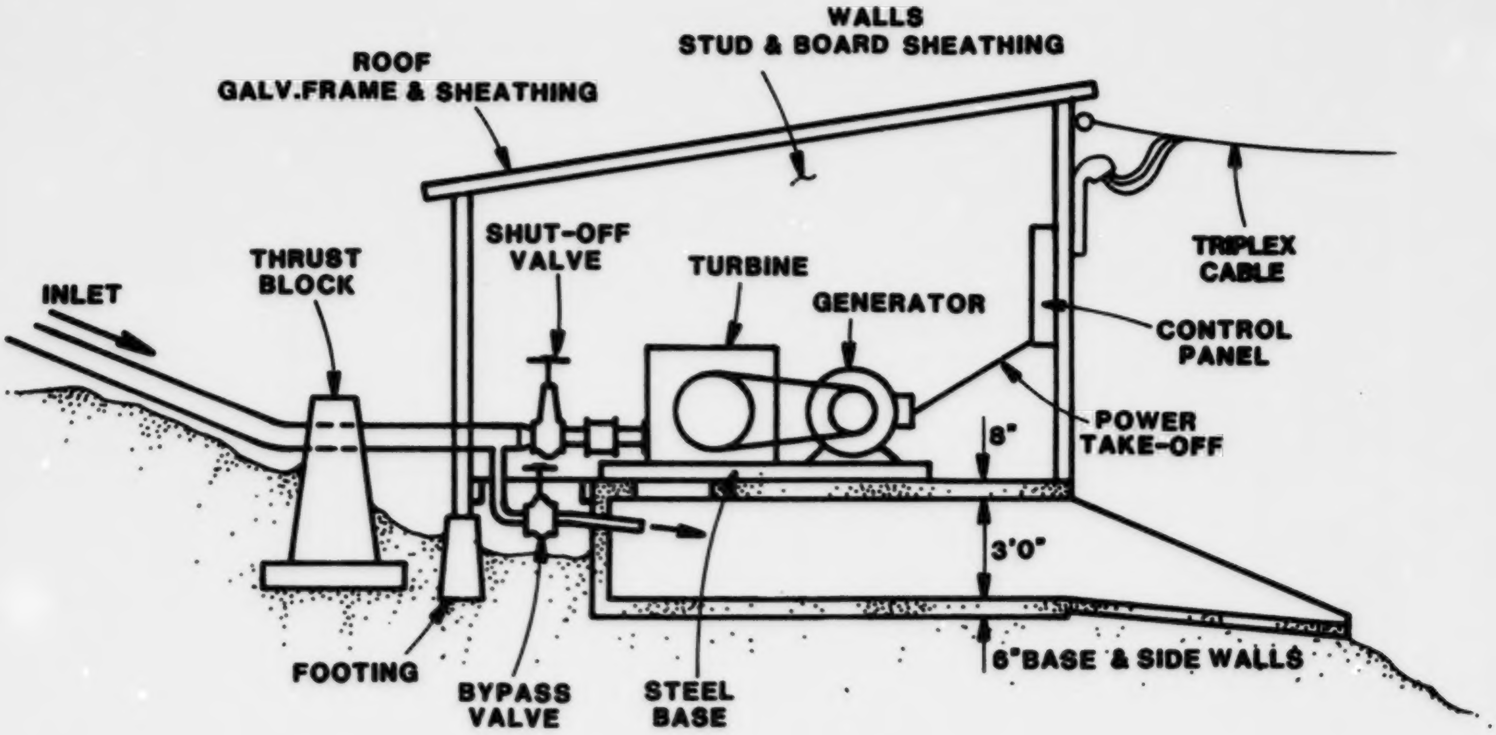

WALLS
STUD & BOARD SHEATHING
ROOF
GALV.FRAME & SHEATHING
SHUT-OFF VALVE
THRUST BLOCK
INLET
TURBINE
GENERATOR
TRIPLEX CABLE
CONTROL PANEL
POWER TAKE-OFF
8"
3'0"
6"BASE & SIDE WALLS
FOOTING
BYPASS VALVE
STEEL BASE

FIG.4-136SMALL TURBINE GENERATOR UTILIZING BOX CULVERT

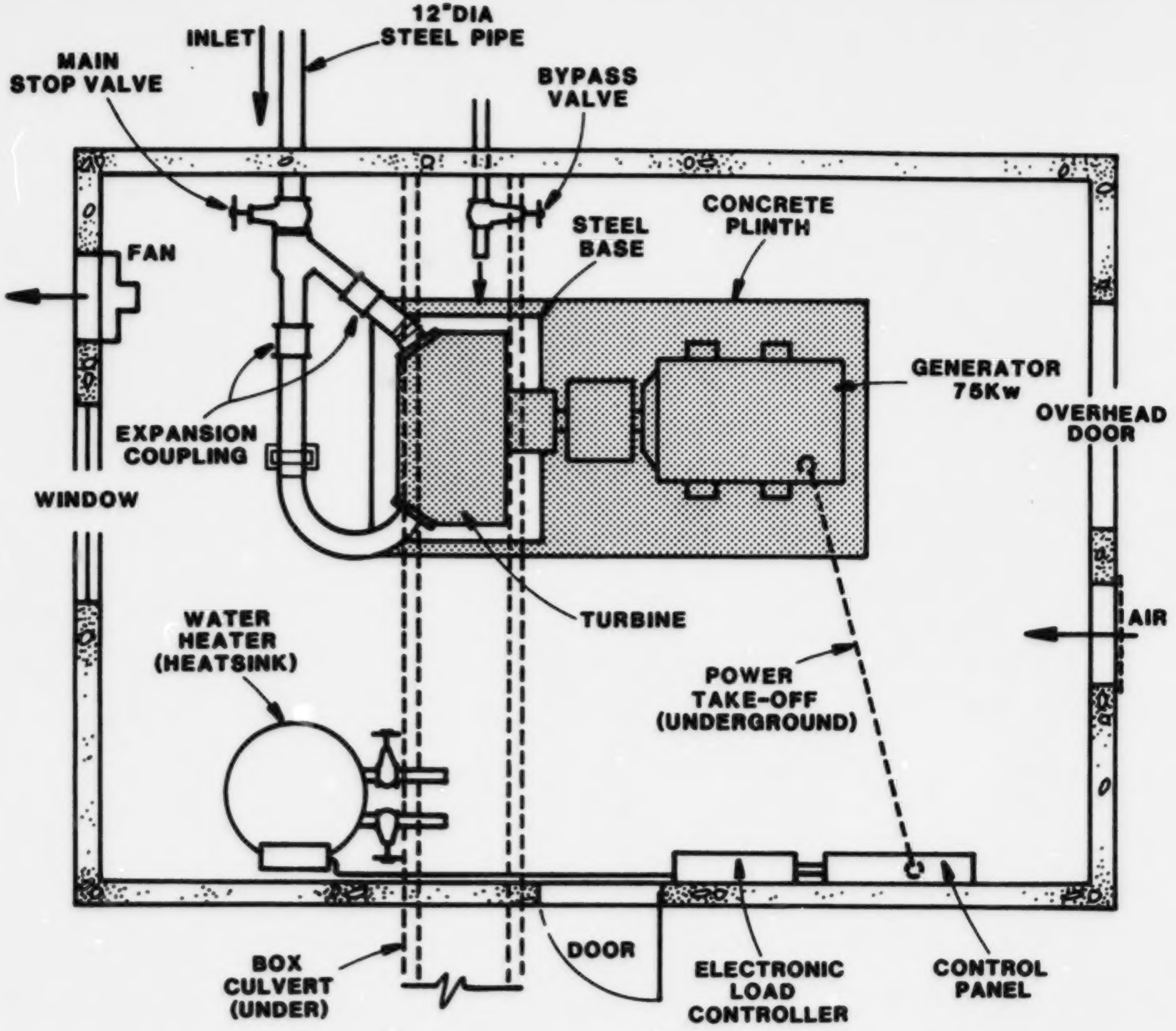

12"DIA
STEEL PIPE
INLET
MAIN
STOP VALVE
BYPASS
VALVE
STEEL
BASE
CONCRETE
PLINTH
FAN
GENERATOR
75Kw
OVERHEAD
DOOR
EXPANSION
COUPLING
WINDOW
TURBINE
AIR
WATER
HEATER
(HEATSINK)
POWER
TAKE-OFF
(UNDERGROUND)
BOX
CULVERT
(UNDER)
DOOR
ELECTRONIC
LOAD
CONTROLLER
CONTROL
PANEL

FIG.4-137TURGO POWERPLANT (75Kw/290'HEAD)

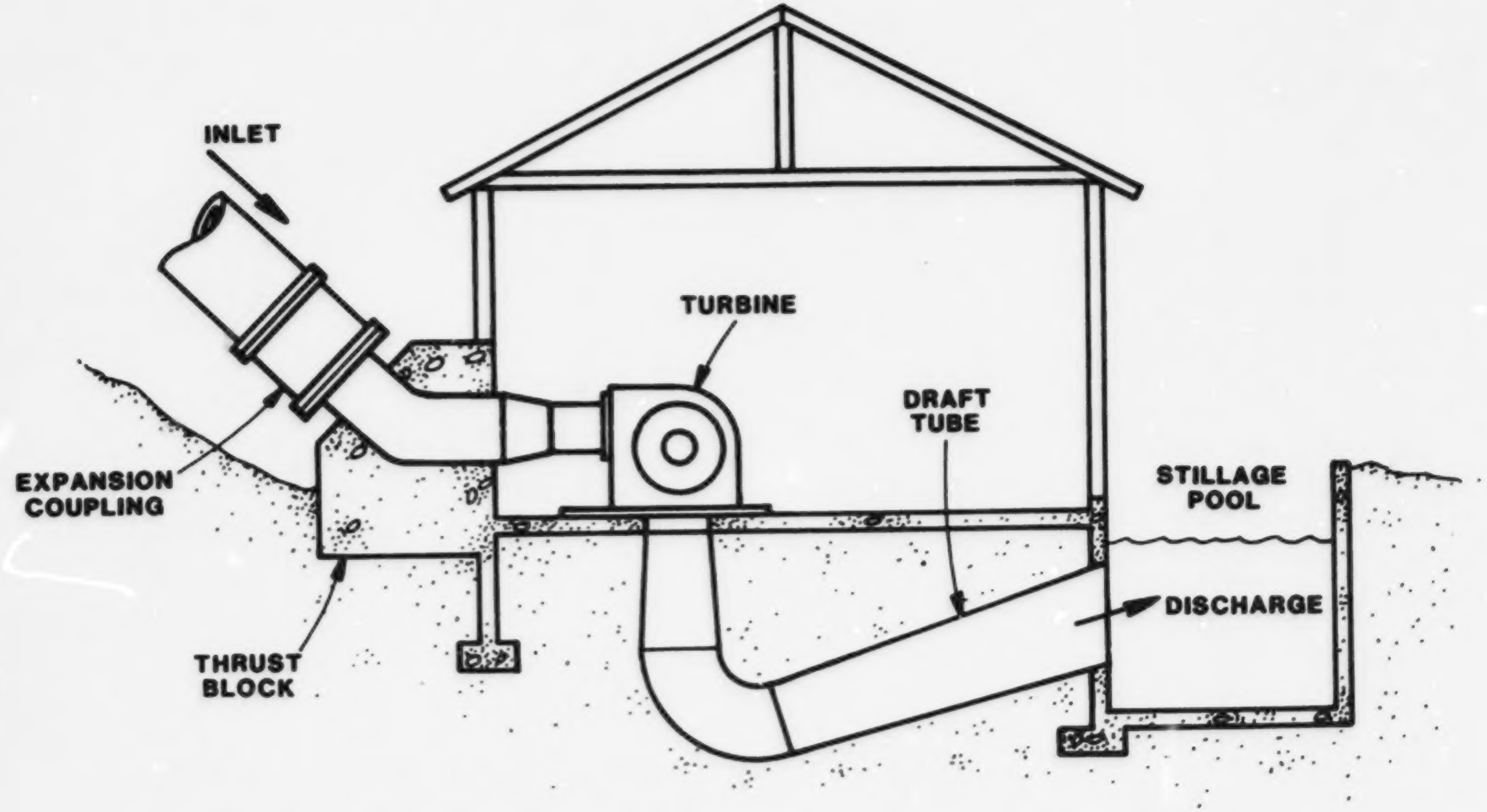

INLET
TURBINE
DRAFT TUBE
STILLAGE POOL
EXPANSION COUPLING
DISCHARGE
THRUST BLOCK

FIG.4-138CROSS FLOW TURBINE POWERHOUSE

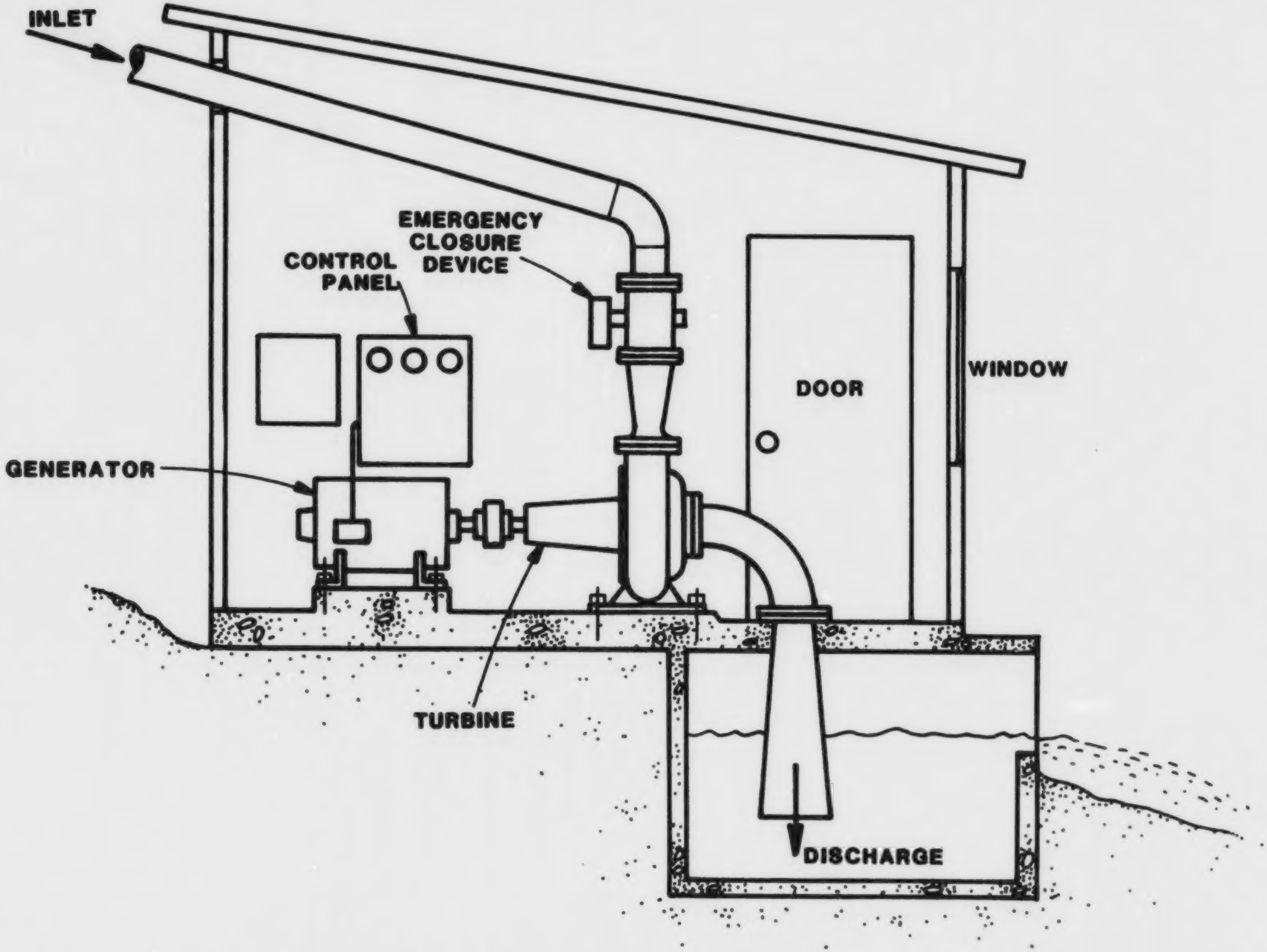

INLET
EMERGENCY CLOSURE DEVICE
CONTROL PANEL
WINDOW
DOOR
GENERATOR
TURBINE
DISCHARGE

FIG.139 FRANCIS OR PUMP TURBINE POWERHOUSE

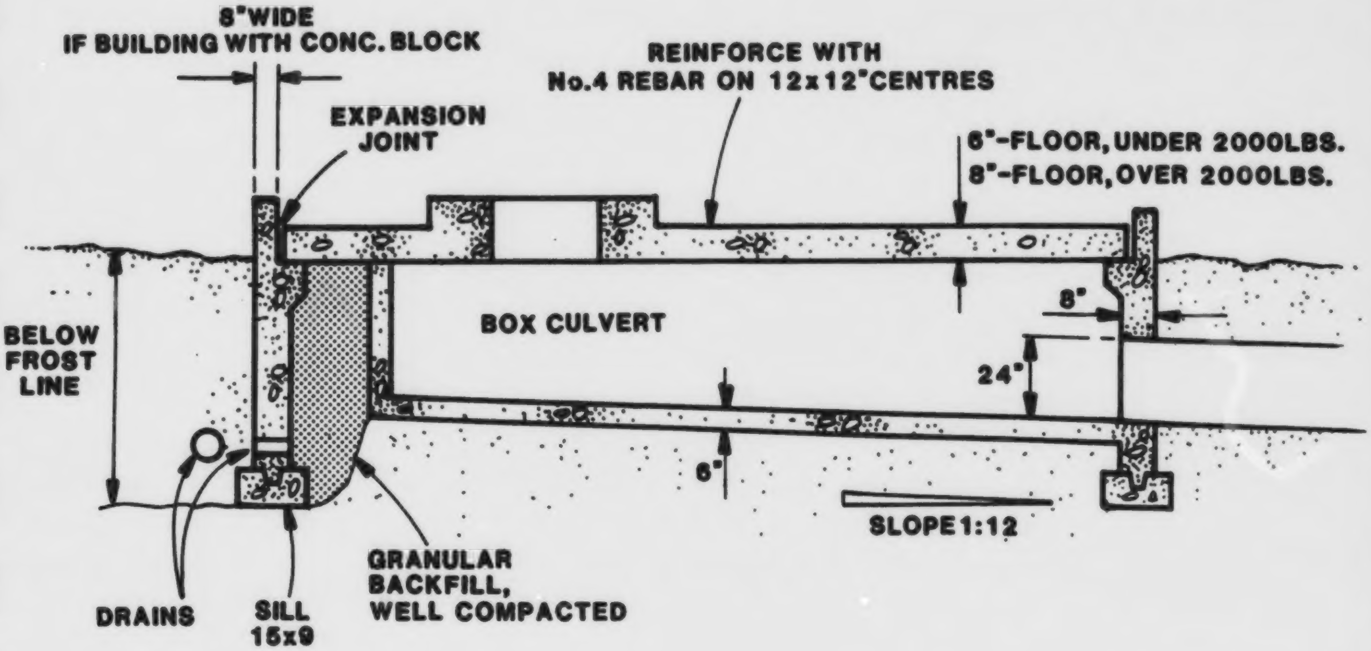

8"WIDE
IF BUILDING WITH CONC. BLOCK
REINFORCE WITH
No.4 REBAR ON 12x12"CENTRES
EXPANSION
JOINT
6"-FLOOR, UNDER 2000LBS.
8"-FLOOR, OVER 2000LBS.
BELOW
FROST
LINE
BOX CULVERT
8"
24"
6"
SLOPE 1:12
DRAINS
SILL
15x9
GRANULAR
BACKFILL,
WELL COMPACTED

FIG.4-140FOUNDATIONS: IMPULSE TURBINE UP TO 100Kw

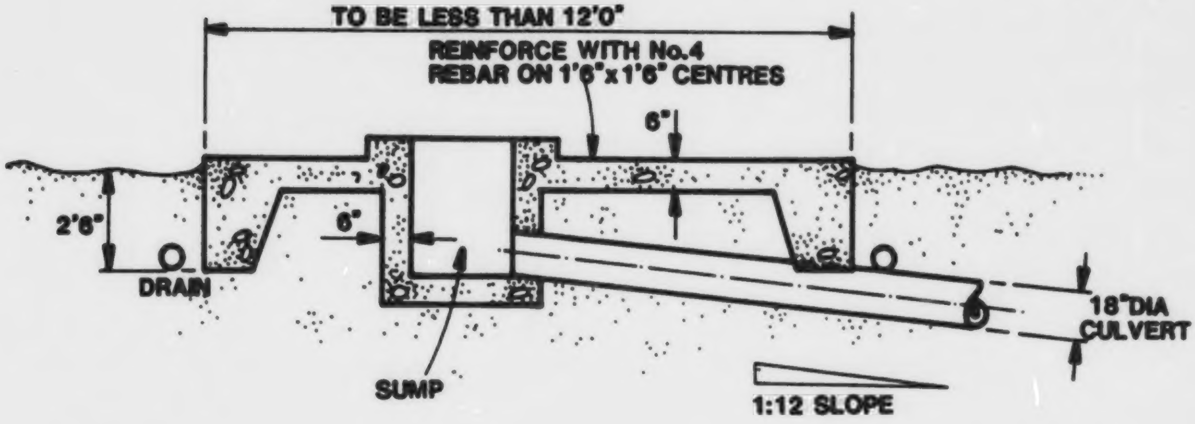

TO BE LESS THAN 12'0"
REINFORCE WITH No.4
REBAR ON 1'6"x1'6" CENTRES
6"
2'6"
6"
DRAIN
SUMP
18"DIA
CULVERT
1:12 SLOPE

FIG.4-141UNIT FOUNDATION: IMPULSE TURBINE UP TO 50Kw

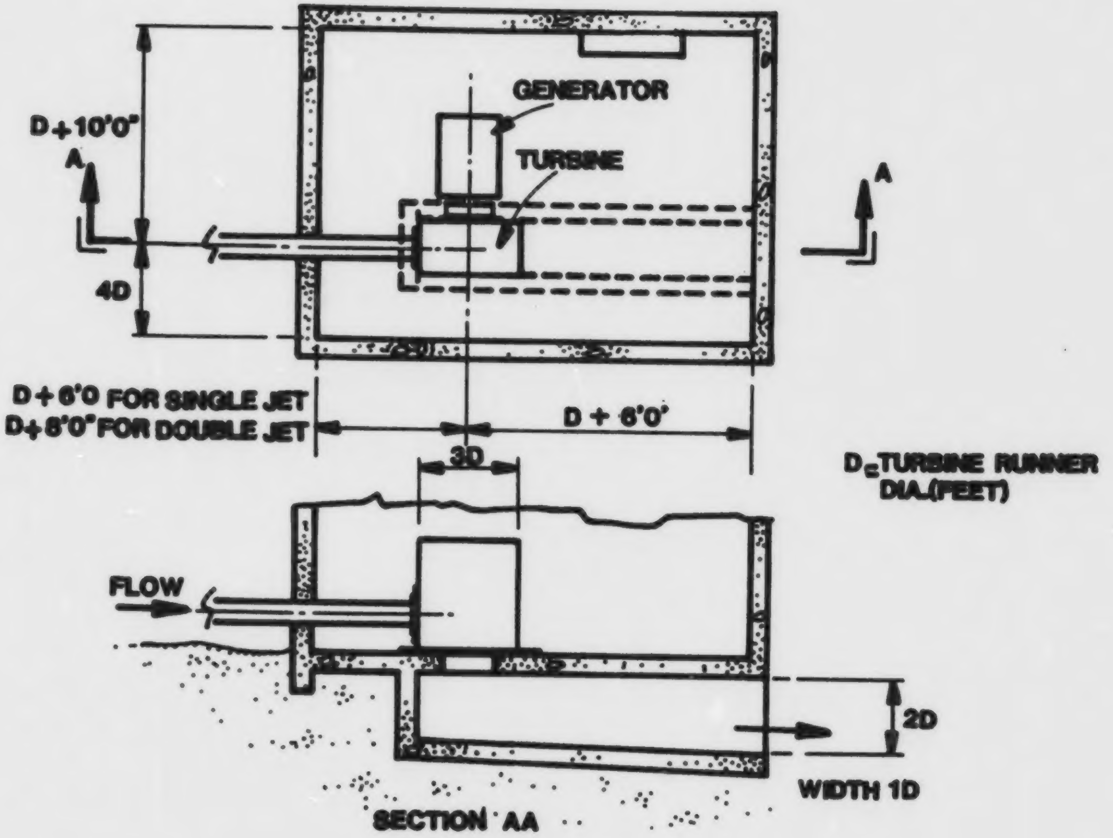

D+10'0"
A
4D
GENERATOR
TURBINE
A
D+6'0 FOR SINGLE JET
D+8'0" FOR DOUBLE JET
D + 6'0'
3D
D=TURBINE RUNNER DIA.(FEET)
FLOW
2D
WIDTH 1D
SECTION AA

FIG.4-142HORIZONTAL PELTON OR TURGO POWERHOUSE

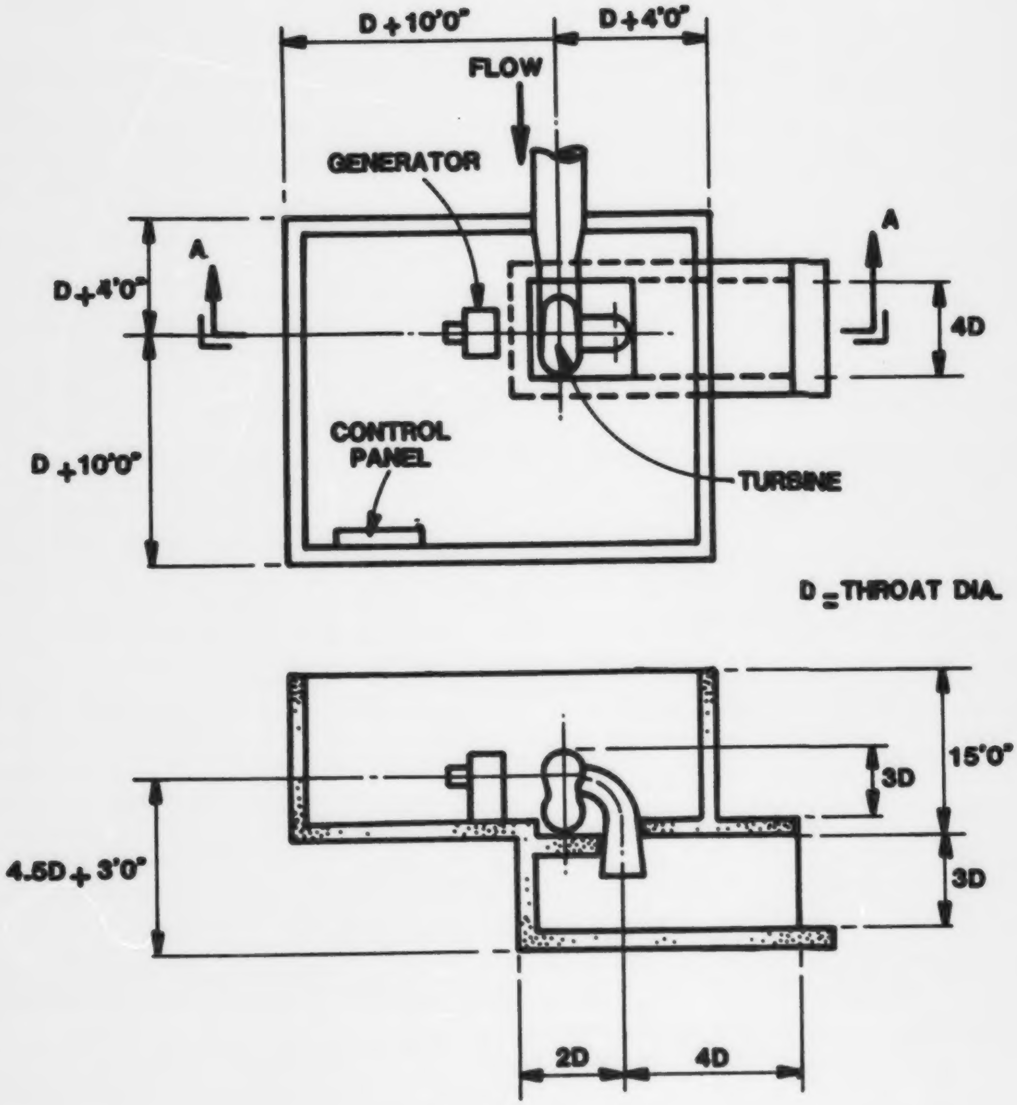
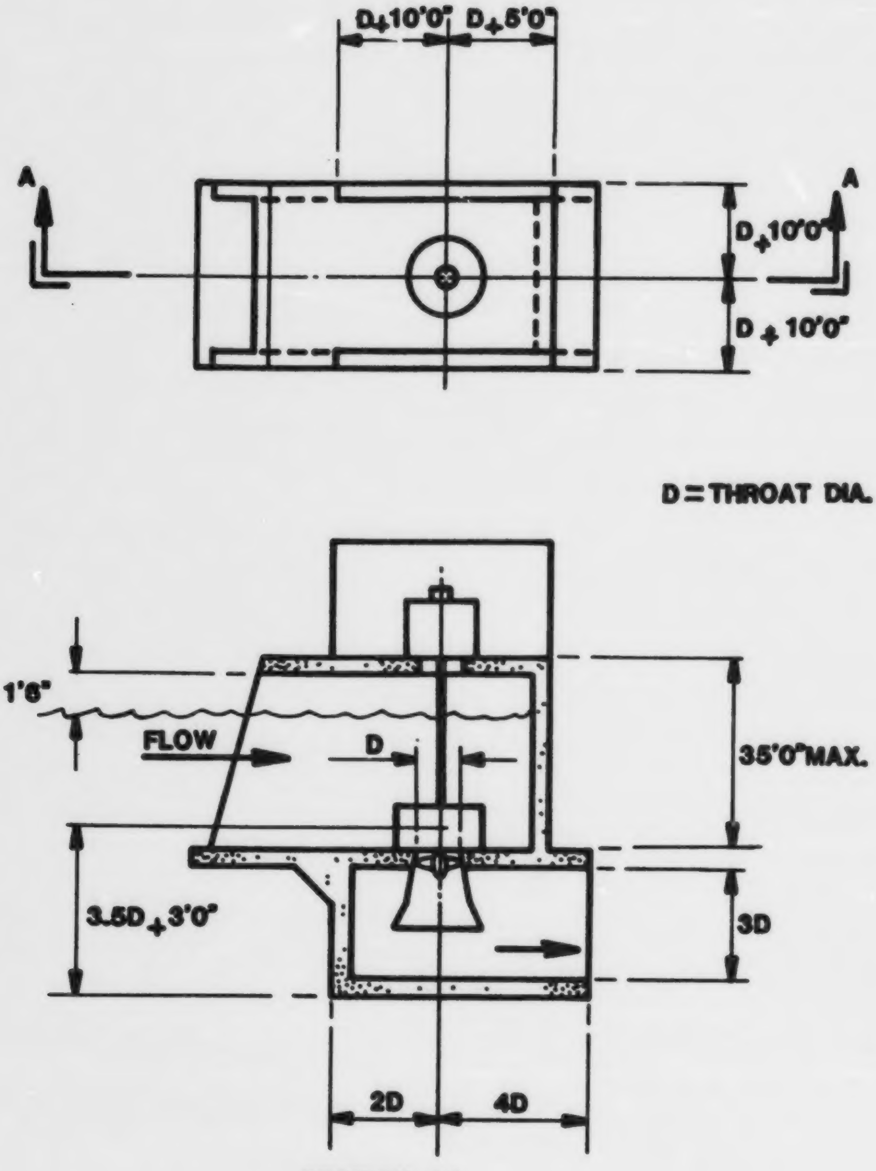
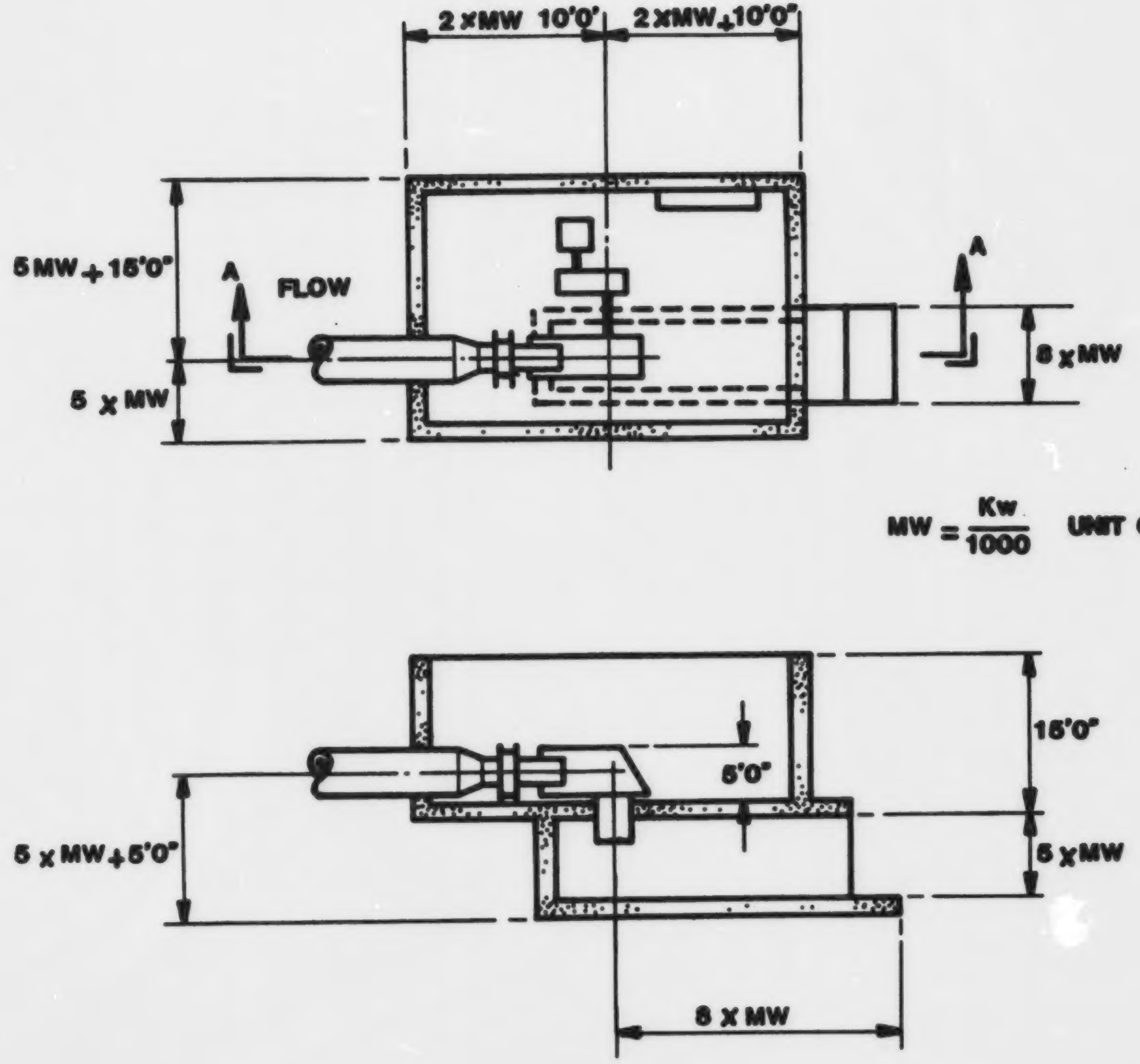

D + 10'0"
D + 4'0"
FLOW
GENERATOR
A
A
D + 4'0"
4D
CONTROL PANEL
D + 10'0"
TURBINE
D = THROAT DIA.
15'0"
3D
4.5D + 3'0"
3D
2D
4D
SECTION AA

FIG.4-143HORIZONTAL FRANCIS TURBINE POWERHOUSE


D+10'0"
D+5'0"
A
A
D+10'0"
D + 10'0"
D = THROAT DIA.
1'6"
FLOW
D
35'0"MAX.
3.5D+3'0"
3D
2D
4D

SECTION AA

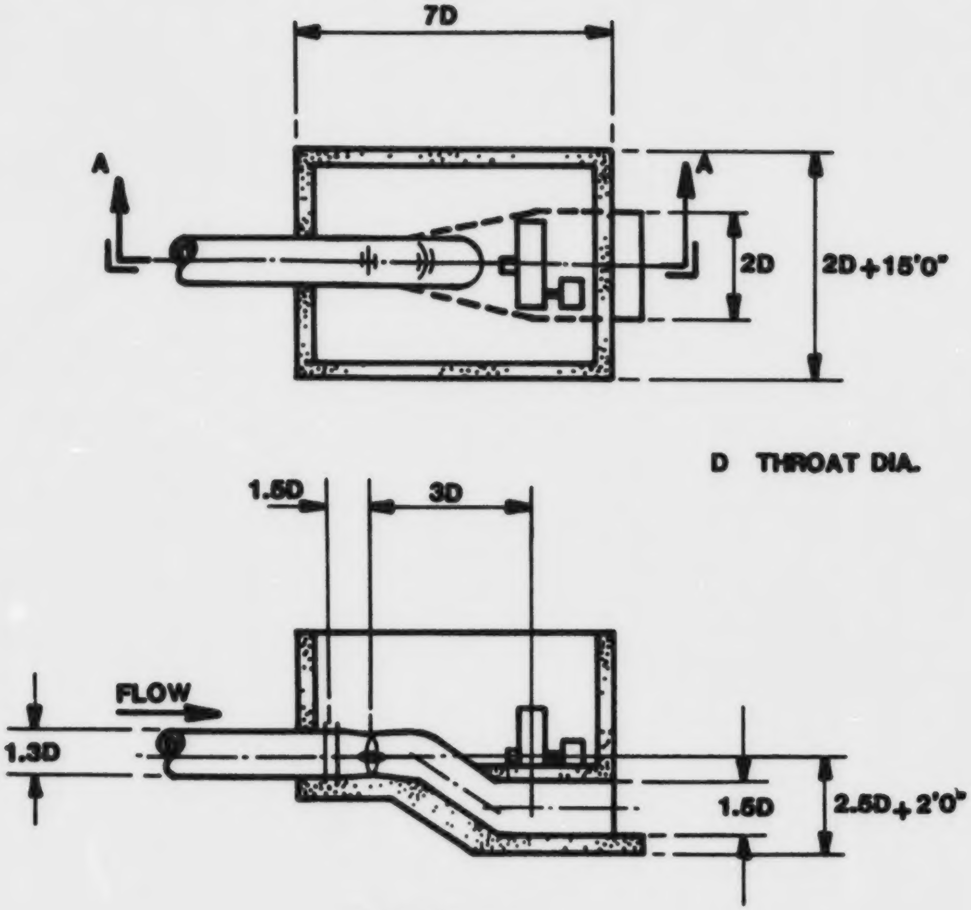
FIG.4-145FLUME TYPE INSTALLATION


2 x MW 10'0'
2 x MW + 10'0"
5 MW + 15'0"
5 x MW
A
FLOW
A
8 x MW
15'0"
5'0"
5 x MW + 5'0"
5 x MW
8 x MW

$MW = \frac{Kw}{1000}$ UNIT CAPACITY

SECTION AA

FIG.4-144 CROSSFLOW TURBINE POWERHOUSE


7D
A
A
2D
2D + 15'0"
D THROAT DIA.
1.5D
3D
FLOW
1.3D
1.5D
2.5D + 2'0"

SECTION AA

FIG.4-146 TUBE TYPE POWERHOUSE

except by dispensing with reclosing, which degrades system reliability and results in a lower standard of customer service. Nevertheless, many utilities in the U.S. are legally bound to accept small dispersed co-generation plants, and a good deal of research and operating experience has led to solutions for most conditions. Some degree of standardization of control and protection features has been achieved.

Basic Requirements For Minimum Protection for 1 kW to 100 kW:

(a) generator circuit breaker with instantaneous and thermal overcurrent elements, and shunt trip coil;

(b) over and under voltage relays with time delay capabilities;

(c) over and under frequency relays with time delay capabilities;

(d) reverse power relay;

(e) battery for circuit breaker tripping power;

(f) dedicated transformer between the generator and Utility;

(g) utility accessible disconnect switch with provision for utility padlock; and

(h) automatic synchronizing equipment.

Additional Requirements For Larger Plants up to 100 kW

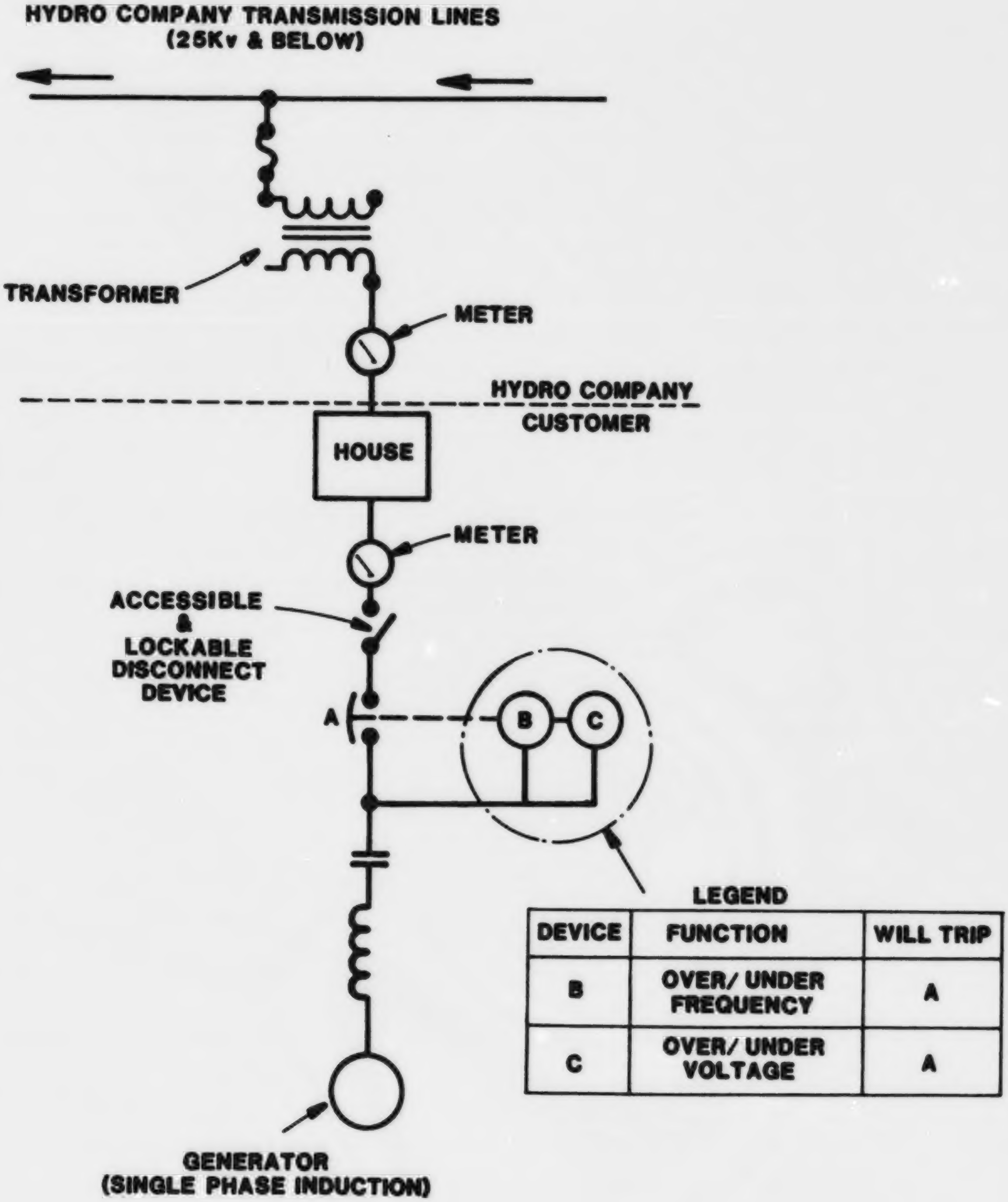
(a) overcurrent relays, one per phase;
(b) ground fault relay; and
(c) zonal protective schemes.

For Induction Generators of Any Size Over and Under Speed Relays

Some utilities may require additional protective features such as differential protection, negative sequence ground fault protection, phase overcurrent with voltage restraint, or other refinements.

Governors For Synchronous Generators

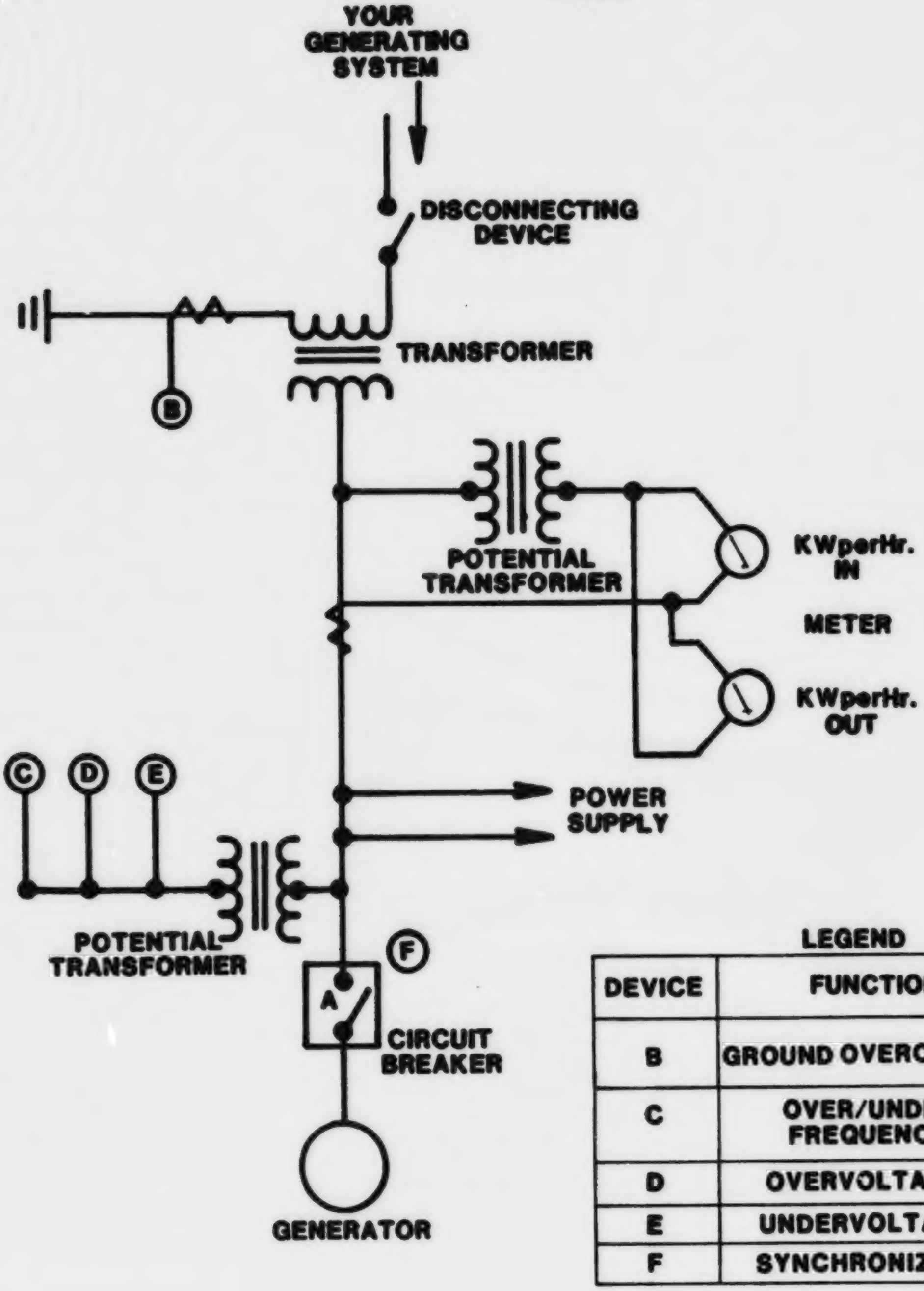
Precise speed control of the prime mover driving a synchronous generator is needed to match frequency with the utility. However, speed control need not be as precise as for a stand-alone generator, because the grid-tied unit is held in synchronism by the magnetic coupling between the rotor and stator. Usually, a droop governor is adequate for interconnected generators. A droop governor normally allows the speed of the generator to change slightly with load. However, where the generator is tied into the utility, speed cannot vary. Instead, the droop governor setting determines how much power is fed into the utility.


HYDRO COMPANY TRANSMISSION LINES
(25Kv & BELOW)
TRANSFORMER
METER
HYDRO COMPANY
CUSTOMER
HOUSE
METER
ACCESSIBLE
&
LOCKABLE
DISCONNECT
DEVICE
A
B
C
GENERATOR
(SINGLE PHASE INDUCTION)

LEGEND

DEVICE	FUNCTION	WILL TRIP
B	OVER/ UNDER FREQUENCY	A
C	OVER/ UNDER VOLTAGE	A

FIG.4-147DIAGRAM FOR LOW VOLTAGE GRID CONNECTION


YOUR GENERATING SYSTEM
DISCONNECTING DEVICE
TRANSFORMER
B
POTENTIAL TRANSFORMER
KWperHr. IN
METER
KWperHr. OUT
C
D
E
POWER SUPPLY
POTENTIAL TRANSFORMER
F
A
CIRCUIT BREAKER
GENERATOR

LEGEND

DEVICE	FUNCTION	WILL TRIP
B	GROUND OVERCURRENT	A
C	OVER/UNDER FREQUENCY	A
D	OVERVOLTAGE	A
E	UNDERVOLTAGE	A
F	SYNCHRONIZING	A

FIG.4-148 DIAGRAM FOR GRID CONNECTIONS: 100Kw OR LESS

Utility Grid Substation

The utility grid substation may consist of a transformer bank located, depending on distance, either at the hydro plant or adjacent to the utility line. A high voltage switch, fuses, and surge arrestors are necessary, together with suitably rated transformers. A voltage transformer (V.T. or P.T.) may be required to monitor the utility line voltage. Utility personnel have access to this equipment, and would disconnect the small hydro line when performing maintenance on utility equipment. Disconnection could occur at any time for making emergency repairs. The utility company will wish to participate at some level in the design, construction, and test of such facilities. They may accept maintenance responsibilities for your high voltage equipment.

Low Voltage Utility Supply

Some utilities permit low voltage interconnections onto the 120/240 volt distribution system, and will purchase excess energy over and above that required for domestic loads. They usually ask for a separate service connection and a separate meter. This kind of connection is limited to a few kilowatts, and no special protection is required. Some type of load controller is necessary to divide the power production between the domestic load and facility. Normally, electronic governing would be the simplest system to use.

Professional Assistance

The utility will make available the necessary technical criteria and engineering standards. Breaking this information into a workable, safe, and economical design requires the services of an electrical engineer. It is preferrable to engage a consultant or engineer to carry out negotiations with the utility to settle engineering details and fiscal matters.

B.C. Hydro Interties

B.C. Hydro is in the process of issuing a guideline for parallel operation: "Guidelines for Operating, Metering and Protective Relaying for Co-generators and Small Power Products."

B.C. Hydro's policy is to permit any customer to operate his generating equipment in parallel with the B.C. Hydro system whenever this can be done without adverse effects on the general public or to B.C. Hydro personnel or equipment. B.C. Hydro requires certain protective devices which disconnect the customer's equipment whenever faults or abnormal conditions occur. B.C. Hydro does not assume any responsibility for protection of the customer's equipment. Faults and abnormal conditions which may develop on the customer's equipment must not cause disturbances on the B.C. Hydro system. Planned interties with B.C. Hydro must be discussed with the corporation at an early stage, as it is not always possible for technical reasons, to accept an intertie at a given locale. In general, all proposed interties are treated on an individual basis so far as types of equipment, protective relaying, and system design are concerned.

B.C. Hydro has four categories for customer interties:

(1) Single phase installations
(2) Three phase installations below 200 kVa
(3) Three phase installations 200 kVa - 1000 kVa
(4) Three phase installations above 1000 kVa

The first two categories are reproduced as follows:

Single Phase Installations

Single phase installation services will be limited to a maximum total generation of 50 kVa.

There must be a manual disconnecting device at the meter. This device is to permit B.C. Hydro to disconnect the customer generation from its system for safety purposes while working on the lines.

Customer generator controls will include a line voltage relay or contactor which will prevent the generator from being connected to a de-energized source. This relay will drop out on loss of voltage and prevent its reconnection until the line is re-energized by B.C. Hydro.

The customer may be served through a dedicated distribution transformer which serves no other customers. The purpose of the dedicated transformer is to ensure that the generator cannot become isolated with a small amount of the customer load. It also serves to confine to the customer's own system, any voltage fluctuations or harmonics produced by the generator.

In order to reduce the possibility of self-excited operation, all reactive power requirements for induction generators or power inverters shall be approved by B.C. Hydro. Except in unusual situations, this supply will be from general utility sources, and up to 50 kVa, no specific charge will be made to the customer for the reactive power. Any required power factor correction equipment must be located on the generator side of the generator switch.

At present, no standards exist for the harmonic output of power inverters. If a customer using such a device for parallel generation is found to be interfacing with other customers or utilities, or if standards are adopted in the future, the generating customer may be required to install filtering to bring the harmonic output of his inverter to an acceptable level.

For all generating installation, existing kW.h meters will be equipped with a detent to prevent reverse registration. Where surplus power sales are anticipated, B.C. Hydro will install additional metering so that kW.h (in) and kW.h (out) are separately recorded.

Metering for kW and KVARH will be determined by the requirements of the individual installation and all additional metering will be paid for by the customer.

Customers should expect multiple reclosing into his service and take necessary precautions to protect his equipment.

Customer shall install, at his expense, items as detailed on Drawing No. ____.

1. Meter Sockets - two standard meter sockets, wired in series, one wired to measure incoming power, the other to measure outgoing power.

2. Visible Disconnect - a visible isolating switch, serviceable by B.C. Hydro lock.

3. Generator Switch - suitable single or multiphase contactor or circuit breaker with holding coil or trip coil for protective tripping and isolation of generator by means of (4).

4. Protective Relay(s) - relay(s) type approved by B.C. Hydro, capable of promptly removing any contribution into faults in the B.C. Hydro system. This shall consist of a minimum of:

   (a) one under and over voltage relay per phase. (± 14 volts)
   (b) one under and over frequency relay per service. (± 1.5 Hz)

Three Phase Installations Below 200 kVa

The following requirements for small generators are based on an assumed low density of parallel generation customers on the serving circuit. Other conditions may be imposed should the density exceed a circuit tolerance.

There must be a manual disconnecting device at meter. This device is to permit B.C. Hydro to disconnect the customer generation from its system for safety purposes while working on the lines.

Customer generator controls are to be equipped with a line voltage relay or contactor which will prevent the generator from being connected to a de-energized source, disconnect the generator from a de-energized utility line, and prevent its reconnection until the line is re-energized by B.C. Hydro.

Customer may be served through a dedicated distribution transformer which serves no other customers. The purpose of the dedicated transformer is to ensure that the generator cannot become isolated with a small amount of other customer load. It also serves to confine any voltage fluctuations or harmonics produced by the generator to the customer's own system.

In order to reduce the possibility of self-excited operation, all reactive power requirements for induction generators or power inverters shall be approved by B.C. Hydro. Except in unusual situations, this var supply will be from general utility sources, and no specific charge will be made to the customer for the reactive power. Any required power factor correction equipment must be located on the generator side of the generator switch.

At present, no standards exist for the harmonic output of power inverters. If a customer using such a device for parallel generation is found to be interfering with other customers or utilities, or if standards are adopted in the future, the generating customer may be required to install filtering to bring the harmonic output of his inverter to an acceptable level.

For all generating installations, existing kW.h meters will be equipped with a detent to prevent reverse registration. Where surplus power sales are anticipated, B.C. Hydro will install additional metering so that kW.h (in) and kW.h (out) are separately recorded. Additional metering for kW and KVARH will be determined by the requirements of the individual installation.

The customer should expect multiple reclosing into his service and take necessary precautions to protect his equipment.

The customer shall install, at his expense, items as detailed on Drawing No. ____.

1. Meter Sockets - two standard meter sockets, wired in series, one wired to measure incoming power, the other to measure outgoing power.

2. Visible Disconnect - a visible isolating switch, serviceable by B.C. Hydro lock.

3. Generator Switch - suitable single or multiphase contactor or circuit breaker with holding coil or trip coil for protective tripping and isolation of generator by means of (4).

4. Protective Relay(s) - relay(s) type approved by B.C. Hydro, capable of promptly removing any contribution into faults in the B.C. Hydro system. This shall consist of a minimum of:

   (a) one under and over voltage relay per phase. (± 14 volts)
   (b) one under and over frequency relay per service. (± 1.5 Hz)

Standby Facilities

Where possible, small hydro plants may be connected to the grid by means of a transfer switch. In this case, a transfer switch is installed so that connection can be made to the utility grid in case of equipment failure, maintenance shutdown, or during low water periods.

The utility grid connection takes the form of a normal service connection made to some convenient central location. A disconnect, meter, and transfer switch are installed, along with a connection to the hydro plant.

The transfer switch must be of a type and manufacture having utility approval. The system as a whole must be approved by the utility company and by the local electrical inspector. Many utilities make a monthly or yearly standby charge in addition to billing for energy consumed.

BC HYDRO POLICIES ON POWER PURCHASES

Policy Status

In June 1988, BC Hydro announced that it would purchase power for its integrated system from Independent Power Producers (IPP's). Subsequently, in December 1988, BC Hydro provided information packages in the following areas:

- Information on Electricity Purchases from Projects greater than 5 MW;
- Information on Electricity Purchases from Projects less than 5 MW;
- Purchase of Electricty in Non-Integrated (diesel) Areas;
- Related connection requirements at greater than 60 kV, and 35 kV and below.

These information packages have been followed up by:

- a Request for Proposals for the supply of electricity to BC Hydro at Fort Nelson, in November 1988;

- a Request for Proposals for the Purchase of Electricty Supply and Load Displacemnt (Projects greater than 5 MW) for BC Hydro's Integrated System, in December 1988:

- a Request for Proposals for Supply of Electricity to BC Hydro at Bella Coola, in March 1989;

- a Request for Proposals for the Purchase of Electricity Supply and Load Displacement (Projects leess than 5 MW) for BC Hydro's Integrated System, May 1989;

- additional calls for proposals are anticipated for other BC Hydro remote diesel facilities, including Telegraph Creek, Dease Lake, Eddontenajon, Iskut, and Kitkatla, after completion of the Bella Coola RFP.

Requirement for Power

The stated objective of BC Hydro is to minimize its cost of electric service. As the electricity surplus of the 1980's declines toward a load/resource balance in 1993, BC Hydro will require additional supplies which it proposes to obtain by purchasing directly from IPP's, purchasing conservation to reduce demand, improving efficiencies at its own plants, through coordination with neighbouring utilities, and by building new capacity of its own. BC's electricity growth rate requires about 100 MW to 200 MW of additional average energy per year, which can be met by a combination of the supply and conservation techniques above. BC Hydro has stated that it has no particular preference for the technology used for the power generation it purchases, other than it must not present any hazards to the existing system, and it must be the most cost-efficient.

Opportunities for Small Hydro Projects

The new BC Hydro policies have provided a greatly increased potential for developers of small hydro projects. The usual definition of small hydro is less than 20 MW, above which an Energy Project Certificate is required by the BC Utilities Commission. However, for the purposes of BC Hydro contracts, there is a division at the 5MW size.

Contracts for Projects Less than 5 MW

The recent experience by BC Hydro has shown that there is a significant transaction cost in a power sales contract, and this is proportionally higher with smaller projects. It is with this in mind that BC Hydro has decided to standardize contracts for projects less than 5 MW. BC Hydro recognizes that individually these projects will not have a large impact on the system, hence the risk of an incomplete project harming BC Hydro or its customers is negligible. Electrical safety standards, reliability, operations and service quality are important to BC Hydro, who will take less of an interest in the actual economic return of the project; placing that risk entirely with the developer.

The payment mechanism is also simple; a flat 3.0 ¢/kWh (1989) for all energy produced, up to a maximum 5000 kW, over a 20 year contract. This price is exepected to rise in consideration of general inflation and the fact that BC Hydro will require new resources within a few years, making energy more valuable. The price is a function of BC Hydro's levelized avoided cost of power, which reflects a 70 year amortization of Site C at a discount rate of 6 percent.

BC Hydro anticipates that up to 25 MW of contracted supply/conservation (under 5 MW) will be purchased in 1989, with an intended contract turnaround time of several weeks between the receipt of proposals after the call and a contract being issued for execution. The call for proposals is exepected to be repeated in the spring of each year for a similar amount of power.

Contracts for Projects Greater than 5 MW

The date for proposals closed May 1, 1989 and up to 150 MW of energy supply or demand reduction may be awarded. Over 1000 MW of proposed energy was received; some proposed projects duplicated those of other proponents. No demand reduction proposals were received.

The contractual and payment terms are significantly different than for under 5 MW projects. The reason for this is that the projects represent significant increments to BC Hydro's system, and their resource plan will depend on the power being delivered in accordance with the contract (but not before 1993). Hence technical and financial capability will be closely evaluated and a completion bond will be required. BC Hydro will use its costs of alternitve capacity addition as a guideline for the maximum price it will pay for energy, but the actual price for power will be modelled on a utility rate of return basis. The developer will receive a fixed rate of return on his investment, paid on the basis of firm energy, secondary energy and firm capacity. Payment will be addressed in those categories consisting of and Investment Component per kWh and per kW,an Operation and Maintenance Component per kWh and a Flow Through Component per kWh, for direct costs which the developer has no control over, such as property tax, insurance, and water rental. The contract will require commitments to the stated capacity, otherwise BC Hydro could re-assess the payment terms and significantly lower the rate of return paid to the developer.

Prior to signing any contracts, BC Hydro will enter a "competitive negotiation" process to ensure that it is receiving the least cost increments of power available. In the over 5 MW contracts, energy sources may include hydro wood waste, waste coal, cogeneration, gas turbine, or load displacement. Until a contract is signed, BC Hydro is under no obligation to the developers it negotiates with.

The two differing contract models may lead to some distortions in types of projects developed, especially in the 5 MW range. The fixed rate of payment may favour undersizing or staged development of some sites because of the risks inherent in the contracting process for projects over 5MW. BC Hydro has indicated that it will not make judgements on the otpimal use of a resource, but that it will allow the developer's business judgement to determine the optimal project size.

Contracts for the Non-Integrated System

There are fewer development opportunities available in the non-integrated (or diesel) system because of the relatively low amount of capacity required; approximately 10 MW among five locations. The proposed contract model is similar to the greater than 5 MW contracts, because such projects will represent a major increment or all of the generation required at each site. If BC Hydro is successful in obtaining proposals at each site, there will be no need for additional supplies, unless some proponents only meet a portion of the total requirement.

Essential Steps in Developing a Hydro Project for Sale of Energy to BC Hydro

The development of a hydro power project for energy sale to BC Hydro involves all of the usual steps in major project development, plus a few additional ones added by BC Hydro. Although the process is simpler for the under 5MW projects, the large of these will involve many of the same elecments as the over 5MW. Project costs of $1 million to $5 million warrant a detailed feasibility study and a financing plan, even though there is no requirement for a review by a financial advisor and BC Hydro intends a less-thorough technical review. Smaller sites, requiring less capital and potentially more of the developer's own labour will be more readily developable because of the simplified contract form they require. The drawback, which is partly overcome by the use of large amounts of the developer's labour, is that there are inherent diseconomies of scale as a project gets smaller.

As noted above, BC Hydro will be primarily concerned with technical and financial capability of the over 5 MW projects. Although there are no rigid guidelines established, the usual requirement for tehcnical capability will be met if the development team has a track record of similar projects, and provides a technical report for the project by a professional engineer, or the developer's own staff, if appropriate. The financial criteria must be met by having a financing plan that is supported with at least offers of funding from bona fide financial groups and is further supported by a letter from one of BC Hydro's selected financial advisors. The developer must arrange and pay for the services of the financial advisor. These technical and financial elements will form the basis of the exhibits that BC Hydro requires in the proposal.

After the proposal is submitted, the developer will have to wait for BC Hydro to first classify the proposals for general acceptability, then rank the proposals to establish a short list for negotiating priority. It is anticipated that two to three months will pass before an invitation to enter negotiations would be received back. Thereafter BC Hydro may assess further charges to defray its costs.

Additional Information

A comprehensive proposal package reference document has been prepared by the Power Contracts group and is available at a nominal cost from BC Hydro.

The latest information on requirements for projects and the status of the negotiating process may be obtained from:

BC Hydro, Power Contracts,
9th Floor, 970 Burrard Street,
Vancouver, B.C. V6Z 1Y3 Telephone: 663-2216

4.36 CONSULTANTS, SUPPLIERS AND CONTRACTORS

In general, small hydro consultants offer a ready and relatively inexpensive means to obtain professional assessment of your site, together with advice on the ways and means required to develop it. They will do as much or as little work as you contract for, and are not apt to land you with high hourly rates and expensive office overheads. This leaves room for your own ingenuity and decision making capabilities.

For most small sites, several levels of study are sometimes necessary, depending upon such factors as size, hydrological and geotechnical aspects, financial analysis, and so on. A brief description is given for the usual kinds of studies, but the number and depth of such studies varies between consultants.

Reconnaissance Study

The reconnaissance study will normally involve a site visit by the consultant, after which you will receive a written report. This report will indicate in general terms whether or not your site is worth further investigation and will lay out the steps to be followed. Further work which you may have to organize may involve a site survey and stream gauging. It is usually possible to determine the approximate locations for the dam, penstock and powerhouse, and to get some idea of the available power. There is not usually sufficient data available at this stage for the consultant to make reasonable cost estimates.

Fees for a reconnaissance study usually amount to two to five days work at a per diem rate, plus travel and accommodation expenses, and a minor sum to cover typing, etc.

Feasibility Study

Most consultants skip the pre-feasibility stage. The main point of the feasibility study is to determine whether or not your site is economic to develop. A fair bit of study is necessary to arrive at reliable figures for stream flow and the most cost effective way of developing the site. Sometimes a site may be too complicated or too expensive to develop, and the consultant will stop the study at this point. All being well, you will get a reasonably detailed site layout, cost estimates, specifications for the turbine generator, and approximate routing for the penstock and transmission line. On smaller sites, where the developer is doing his own construction, this information package is sufficient to proceed to construction unless substantial dams or other large scale items are involved. In this case, the consultant will write design specifications for these components and suggest an engineer to carry out the finished design. Any specialist work, such as hydrological or geotechnical surveys, will be discussed with you prior to engaging outside personnel.

You may not need to purchase the full feasibility study. If you can define just what aspect of the work you feel unsure about, you can have the consultant deal with that point. Most consultants will wish to review the work as a whole, however, to make sure that the scheme is a viable one. For instance, asking the consultant to draw up a specification for a certain size of turbine is futile when he can see for himself that you do not have sufficient flow for it. Feasibility studies are usually conducted at a per diem rate, plus actual expenses. The consultant can only submit a price for this after making a site visit, so that the reconnaissance stage must usually come first. Time and costs are a matter for negotiation between you and the consultant, and the best place to do this is on your territory. A good way to save time and money is to do your own stream gauging and survey work; but keep in mind that this work must be reliable and accurate. However, the consultant may require a disclaimer if he is expected to work with your figures.

Detailed Design

Certain consultants do not usually perform detailed design work because various disciplines such as civil, electrical, and hydraulic engineers may be needed. Most large companies and government agencies will require sealed engineers drawings. This level of design is normally required only on larger sites, somewhat above 200 kW. In this circumstance you can retain the consultant to act as a go between on your behalf. He will, if desired, select the engineers or engineering firms, coordinate the work, and maintain cost control during the design phase. You must determine the necessary level of design and ensure that the time and effort spent on the design is commensurate with the size of the project and within the budget. The consultant can act as a referee in cases of conflict.

Some consultants will accept commissions for site inspection services during construction. In this role, they will enforce quality control and adherence to specifications, and will witness the construction and testing of turbines, generators, etc.

The main areas where responsibility could be questioned are third party damages arising out of the work or any failure of the work, failure of the plant to live up to reasonable expectations, or underestimated costs. You should clarify with legal counsel your position with regard to the possible risks. You may wish to ensure against a variety of possible loss scenarios during and after construction, and you should discuss these aspects with an appropriate insurance firm.

Professional engineering services become necessary, at least for a part of the work, on sites above about 200 kW to 500 kW. Detailed professional design work may be necessary for dams, structures, buildings, and certain other aspects of the work. In the size range above 1000 kW or so, it often becomes economic to have the whole of the feasibility study and the detailed design work done by an engineer or engineering firm. Full scale engineering costs are usually between 12 per cent and 17 per cent of the total capital cost.

Purchasing

Make an exact list of your requirements down to the last detail, and get prices and delivery charges from two or three firms. There are price advantages in package deals, and it is almost always cheaper to deal with a single source. There is quite a lot of industrial surplus and used equipment around, such as used steel pipes, valves, fittings, miscellaneous steel shapes, reinforcing bar, bolts and so on. If you know what to look for, you may be able to rack up substantial savings. Use only new or guaranteed rebuilt valves, at the powerhouse end. Expansion joints must be new, and if the penstock pressure is above 150 psi, use new pipe until the pressure is less than 75 psi when good used pipe may be used. Do not use second hand plastic pipes or fittings as these could have been overstressed by water hammer or general abuse at some point.

Use ready mix concrete where available. The vendor will suggest the best mix, which should be heavy on cement. Do not bother with slump tests unless structural concrete such as beams are involved, or unless the engineer or consultant requires such tests.

There is a wide range of prefab buildings available, either new or used. These are worth pricing, as they may be cheaper than putting up your own building. They are normally designed to fit onto a slab or perimeter wall which must be built to fit the building.

If you are doing your own electrical work, divide the work up into packages, and purchase these lots as you need them. Electrical equipment is expensive and this procedure minimizes waste. Stay away from used electrical equipment and wiring, except for such things as conduit and overhead line materials, which are generally reusable. Surplus new equipment is sometimes available.

Many electricians, pipe installers and contractors prefer to supply the necessary materials. They usually make a 10 per cent or more mark-up on materials as they purchase at wholesale rates. For your own protection, you should find out in advance what the cost of these materials is, so that you can check your invoices. Insist on itemized invoices showing the cost of all materials used.

Many wholesale equipment and parts dealers require a provincial tax number before they will deal with you. You can apply for a provincial tax number to meet this requirement. You should argue with firms for a discount: you will be impressed by how much lower trade prices are.

Do not be tempted to purchase used equipment which needs fixing, unless the work is very minor. Making such repairs invariably occupies time which could be better spent moving your project forward. Rebuilt equipment is generally acceptable, provided it comes from a reputable firm willing to guarantee it.

If possible, discuss your requirements with one or more firms. Their familiarity with standard practices and the equipment availability can often lead to cheaper and better alternatives. Insist, however, that design requirements such as pressure rating of pipe, are maintained.

Contractors

The usual varieties are:

- Earthmoving, excavation and haulage
- Cement work, usually including concrete block
- Building, timber or concrete block
- Electrical
- Insulation installation
- Pipe installation
- Machinery installation

On larger jobs, there will usually be one general contractor who will let some of the work out to sub-trade contractors. Some of the smaller contractors will do most or all of the work on small jobs.

Hiring individual tradesmen is easy and convenient, and may be sufficient for small installations.

On small jobs, get fixed prices for sections of the work from several contractors. You should divide the work into packages similar to the above headings, and provide drawings and specifications for each. Discuss civil works such as dams and foundations with the Contractor on site, rather than relying on ballpark costs for such projects as moving so many cubic yards of material. Difficulties can arise with all contracts when the work is not clearly described, or the intent of the work is not understood in mutual terms between the client and contractor. Insist on signed contracts however simple they may be. Details should include who is responsible for the supply of materials, delivery charges, permits and fees.

The best contractor is the one who fully understands the work and is professional in his approach and dealings. Under-bidding on jobs always leads to poor work and shortcuts, and you should reject bids which appear too low in comparison with the others. Avoid cost plus contracts. The contractor is entitled to a profit of 10 per cent to 15 per cent plus a reasonable profit on the materials he supplies.

Do not expect the contractor to do your design work. It costs a lot in terms of money and wasted time if you and he must stand around figuring what to do next. There will, of course, be times when decisions must be made and alterations are necessary, but thorough planning will keep these to a minimum.

4.37 SPECIFICATION FOR MICRO HYDRO INSTALLATIONS

Data Sheet

Power required	30 kW at 0.8 power factor
Receiving end voltage	115/230V
Phase	1
Overall hydraulic head	440 feet
Pipe loss	40 feet
Net head at turbine	400 feet
Type of turbine	Pelton
Type of drive	V-belts
Generator speed	1800 rpm
Type of Governor	Electronic with water control
Type I enclosure	Portable skid mounted unit
Type II enclosure	Installation inside timber building
Penstock	8 inch diameter PVC
Length of penstock	1300 feet
Bypass valve	3 inches
Emergency shutdown	Jet deflector
Power line	2300 volts, 1-phase, 3/4 mile

Steel section of penstock into powerhouse

The specification following covers the installation of an actual small hydro unit and was originally issued with drawings and technical specifications for the turbine generator.

SPECIFICATION FOR MICRO HYDRO INSTALLATION

ADDENDUM NO. 1

General

This addendum details site specific features and requirements, and is to be read in conjunction with:

- Specification for Micro Hydroelectric Unit
- Drawing No.
- Drawing No.
- Drawing No.
- Site specific data sheet
- Client's Terms of Reference and contractual requirements.

It shall be noted that the drawings are conceptual in nature, and the responsibility for verifying site parameters or determining suitable alternative parameters lies with the Contractor/Vendor.

Alternative details and construction may be offered. All such changes shall be subject to approval by the Client's engineer at the tender stage. Changes which appear necessary or desirable during the construction period require similar approval prior to implementation.

1.0 Scope of Work

The scope of work constitutes the provision of a micro hydroelectric unit in accordance with the specification and installation of the unit on site. Included in the scope is provision and construction of the following items:

- Micro Hydro unit
- Dam and intake
- Penstock
- All necessary civil works, foundations, thrust blocks and access roads.
- Building enclosures where necessary
- Power transmission line where necessary
- Load controller
- Water control module and associated cables where indicated
- Transfer switch where indicated
- Such other features as may be called for in the specification and/or drawings or are reasonably necessary to complete the work.

The aim and object of this specification is to obtain a fully functional micro hydro unit at the location specified, complete and operational in all respects.

SPECIFICATION FOR MICRO HYDRO INSTALLATION

ADDENDUM NO. 1

1.1 Items not Included

The dumping system for the load controller. However, the Vendor shall develop a suitable scheme, taking into consideration all local site conditions, in consultation with the Client's engineer. This scheme will be implemented as an extra to the main contract.

2.0 Civil Works

Provide the following:

2.1 Access road.

This is provisionally located on the drawings. Construct single lane unpaved road into the power plant site. Fall any danger trees.

2.2 Penstock

Provide all necessary foundations and thrust blocks. Construct penstock on the straightest reasonable line. Use gradual bends wherever possible. Do not use factory bends over 30°, nor allow pipe to sag appreciably between supports. Fall any danger trees, but do not clear right of way.

2.3 Pipeline Foundations

Construct pipe supports and thrust blocks using Damsack or approved equal.

2.4 Dam and Intake

Construct using Damsack. Install rebar ties and anchors as outlined on the drawings. Provide at least a 6 feet depth of water above the intake.

Provide intake box with screened trash rack and secondary screen on pipe intake. Provide for water control module. Obtain prior approval for alternate type of dam such as rock fill or timber crib.

2.5 Power Thrust Block

Provide thrust block at powerhouse and locate expansion joints such as to relieve power plant of pipeline expansion and contraction loads.

2.6 Foundation

Provide power plant foundation to suit Type I or Type II whichever is specified.

2.7 Enclosures

Provide building enclosure if Type II is specified.

2.8 Other

Provide enclosure if necessary to house Load Controller, transfer switch and power line disconnect switch.

3.0 Mechanical Works

3.1 Penstock

Use ASTM designated pipe to suit hydraulic loads at site. Design in accordance with "Handbook on PVC Pipe", Unibell Plastic Pipe Association, or equal industry handbook. Piepline may be butt fusion welded for the main pressure section. The upper penstock reaches may be solvent cemented.

Special attention shall be given to the plastic to steel connection near the power plant. If desired, this joint may be encased in a concrete thrust block.

3.2 Ventilation

Type I:

Supply insect proof screens of large area for inlet and exit air supply. Treat soil around air exit such that plant growth will not obstruct vent.

Type II:

Install vent fan with thermostat in roof peak. Set to 65°F. Furnish screened air vent louvre in wall of building. Minimum clear opening 0.3 m^2.

In Type I building, permanently install a small oil heater. This should be capable of maintaining interior at 60°F during winter plant shutdown, should this occur.

SPECIFICATION FOR MICRO HYDRO INSTALLATION

ADDENDUM NO. 1

4.0 Electrical

4.1 Power Line

Supply, if feasible, locally cut poles. Align power line along side of access road. Do not clear cut right-of-way but lop interference trees and fall danger trees. Sag in accordance with sag table for size and type of conductor (see Alcoa Handbook or B.C. Hydro Transmission Design Standards). Guy where necessary.

Ground neutral and install arrester at each end as shown on the drawings. Comply with CSA standards for overhead power line in respect to clearances over roads.

4.2 Standards

Comply with Canadian Electrical Code C22.1, 1982 Part I, and C22.3, No. 1.

4.3 Diesel

Existing diesel will be retained as standby. Provide transfer switch and necessary electrical details to permit diesel to carry load when necessary.

5.0 Building Housing

For Type I units, supply a timber or metal clad building. Insulate for R12 and line with 5/8 plywood or plaster board. Install two wired glass windows 600 x 1000 and a 1200 mm wide door. Paint interior and exterior. Install substantial hasp and padlock. See Section 3.2.

6.0 Testing

Pressure test penstock at 1½ times penstock static head for 5 minutes. Repair any leaks or disturbed foundations. Conduct tests as outlined in Section 7.2 and 10.1, Micro Hydro Unit Specification.

7.0 Condition of Contract

The condition of contract laid out in Section 10, Micro Hydro Unit Specification, applies to this addendum.

GENERATOR SPECIFICATION

A.C. Generators up to 50 kW for Small Hydro Use

Rating	
KW at 0.8 pf	
Phase	
Voltage	
RPM	
60 Hertz	
Service Factor	
Synchronous	
Asynchronous	
Stator Winding	
1-phase 4-lead	
3-phase 12-lead (Supply grounded wye on 3-phase)	
Rotor	
Overspeed rating	%
Amortisseur winding required	
Voltage Dip	
Non-motor starting on application of full rated load	
10%	
20%	
Voltage Dip	
Motor Starting (see attached list) on starting largest motor	
10%	
20%	
30%	
Residual load prior to starting motor. See general specifications	kW
Standards	
Generator to comply with NEMA MG-1, Part 22, 1978 and CSA Standard C22.2, 1982	

Construction	
2-bearing	
1-bearing	
Horizontal	
Vertical	
Open protected	
Drip proof	
General arrangement drawing requested	
Bearing	
Lubricated for life*, 40,000 hour B10 life	
Regreasable with grease pipes and fittings, 50,000 hour B10 life	
*Not above 15 kW rating 1800 RPM	
Insulation Class	
Supply Class F insulation system. Temperature rise shall conform to NEMA MG-1, Part 22, 1978 for continuous duty	
Controls and Instruments	
Supply	
Voltage adjusting rheostat	
Field circuit breaker	
Voltmeter and switch	
Ammeter and switch	
Hertz meter	
Winding thermostats for 140°C trip and 160°C trip with relay	
Mount above items on generator	
Supply loose for panel mounting	

GENERATOR SPECIFICATION
A.C. Generators from 50 kW to 250 kW for Small Hydro Use

Rating
KW at 0.8 pf
Phase
Voltage
RPM
60 Hertz
Service Factor
Synchronous
Asynchronous

Stator Winding
1-phase 4-lead
3-phase 12/24 lead
3-phase winding shall have 2/3 pitch to minimize third harmonic content

Rotor
Overspeed rating %
Amortisseeur winding required

Voltage Dip
Non-motor starting on application of full rated load
10%
20%

Voltage Dip
Motor Starting (see attached list) on starting largest motor
10%
20%
30%
Residual load prior to starting motor

Standards
Generator to comply with NEMA MG-1, Part 22, 1978 and CSA Standard C22.2 100M 1982

Other
____
____
____

Construction
2-bearing
1-bearing
Horizontal
Vertical
Open protected
Drip proof
General arrangement drawing requested

Bearings
With provision for changing grease through grease fittings extending to generator exterior

Minimum 50,000 hour B10 life up to 75 kW. Minimum 100,000 hour B10 life above 75 kW. Rating are for direct coupled horizontal installation

Insulation Class
Supply Class F insulation system. Temperature rise to conform to NEMA MG-1, Part 22, by resistance method for continuous duty

Controls and Instruments
Supply
Voltmeter and switch
Ammeter and switch
Hertz meter
Field circuit breaker
Winding thermostats for 140°C trip and 160°C trip with relay
Series boost for at least 250% of full load amperes for 3 seconds
Mount above items on generator
Supply loose for panel mounting
Regulator:
Volts per Hertz
Constant Voltage
Combination
Mounting

PERFORMANCE - GENERAL SPECIFICATIONS

- Regulation to within 1% no load to full load, voltage drift less than 1% per 40°C temperature change.
- Harmonic content shall not exceed 5% RMS line to line.
- Telephone interference factor 50 or less.
- Radio interference protected to industry standards.
- Balanced to within 2 mils.
- Voltage rise on full load rejection and overspeed condition shall not exceed 15%.
- Excitation system shall consist of a brushless exciter with rotating rectifier. Supply selenium surge protectors. Rectifier assembly shall be replaceable without dismantling the generator.
- Control and junction box load connections shall be possible on the top, sides, or bottom of junction box.
- Supply volts per hertz compensated for regulator for motor starting duty or where specified. The volts per hertz characteristic shall be operational at under 90% rated terminal voltage.
- Series boost when specified, shall maintain a short circuit current of 250% of full load amperes for 3 seconds.
- When vertical mounting is specified, coordinate weights and thrust loads with turbine builder.

Load Characteristics

Motor Starting

1. _______ HP NEMA Letter _______
2. _______ HP NEMA Letter _______
3. _______ HP NEMA Letter _______
4. _______ HP NEMA Letter _______

When NEMA Letter is not specified, assume 6 kVA per HP. Assume that motors will be sequentially started, the largest one first unless otherwise specified.

- Computer communications on SCR devices, specify:

Alternatives

The Vendor may submit alternative manufacturers standards, provided that they do not compromise CSA standards or the useful life of the equipment. All such alternatives shall be approved by the client's engineer prior to manufacture.

TURBINE SPECIFICATION

For the Supply of a Hydraulic Turbine Only

End Use
Generator
Mechanical Drive

Hydraulic Conditions
Useful Head
Flow
Variation in Head
Maximum
Minimum
Preferred RPM

Penstock Details
Length
Material
Diameter

Calculated Head Loss

Flow Conditions
Constant
Variable, see details on separate sheet
Turbine builder to check pipe, friction loss, water hammer, and suitability of the penstock
Yes
No

Balancing
Balance turbine shaft and rotor to within 2 mils.

Construction
Horizontal
Vertical
V-Belt Drive
Direct Coupled
Fixed Nozzles
Jet Deflector
Spear Valve
Wicket Gates
Open Flume Type
Spiral Casing
Other

Preferred Type
Pelton
Turgo
Crossflow
Francis
Propellor
Kaplan
Pump Turbine

Generator Rating if used
kW at 0.8 p.f.
RPM
Rotation C.W.
Rotation CCW
(Viewed on shaft end)
Manufacturer
Serial No.
Shaft Diameter
Size of Keyway
NEMA Frame Size
Supply V-Belt Drive
Supply Coupling

Usual Makes of Generators

Kato
Marathon
ASEA
General Electric
Brush (Hawken Siddelod)

Stamford
Pincor
Houchin
Eliot

Kohler
Caterpiller*
Electric Construction Co.
Brown Boveri
ONAN

Fidelity
LIMA
Reliance
Delco

* Factory tested to 50% overspeed which makes it a good choice for use with Centrifugal "pumps and turbines" which will not exceed this speed or runaway.

TURBINE OPTIONAL EQUIPMENT

For Small Hydro Turbine 250 kW or Less

Governor, Generator Drive
Supply
Mechanical
Electronic
Electronic with water Control

Draft Tube
Supply fabricated steel draft tube

Supply Tube Assembly for Propeller Turbine

Emergency Shutdown
Supply Jet Deflector Trip

Tachometer Generator

Plugging Switch

Other, Specify

Generatory Flywheel
Supply
To specified WK2

Details ______________________

____

____

How Mounted ______________________

____

____

Installation
Turbine builder to install, align and test run the turbine
Yes
No

Protective Gear
Supply
Lube Oil Temp Alarm(s)
Ditto Low Oil Level
Bearing Temperature Alarms(s)
Vibration Monitor(s)
Shock Pulse Meter
Other

Electrically Operated Turbine Stop Valve
Supply
Electrically operated Gate Valve
Supply Voltage, D.C.

Torsional Analysis
Supply
Torsional Analysis for Turbine/Generator Assembly

Paralleling
Turbine to operate generator in parallel with one or more generators

Types of Governors ______________________

____

____

Other Details (separate sheet)

Base Plate
Supply fabricated bed plate for turbine only ________
For turbine and generator ________
Slide rail base for generator only ________

GENERAL SPECIFICATIONS (IMPULSE TURBINES) 250 kW OR LESS

Supply cast iron or fabricated steel housing. Structural ridigity of housing to be commensurate with operating stresses and size of turbine. Welded assemblies shall be stress relieved. The casing design shall permit easy access to the turbine runner, bearing and nozzles.

Turbine runner shall be constructed of sound castings or fabricated assemblies. Material specifications shall be in accordance with industry standards. Supply ASTM type 304 stainless steel runners on heads above 330 feet.

Bearings shall be rated at least B10 50,000 hours. Bearing housings shall be located outside of the turbine casing, with adequate provisions for keeping water away from the bearings.

Do not supply water cooled bearing housings. When cooling is required, provide an oil circulating system with a shell and tube heat exchanger fed with cold water from the penstock. Supply an ample oil reservoir tank with low oil level alarm and trip. Provide for thermometer installation in bearings.

Runner shall be securely mounted on the shaft using ring fitters or approved equal.

The shaft and runner shall be statically and dynamically balanced to within 2 mils.

Turbine efficiency may conform to manufacturers' published data, but shall not be less than 80% at 3/4 rated full load.

Flywheel shall be mounted on the generator shaft up to the load rating of the generator bearings. Above that size, supply a 3-bearing turbine design. The drive end bearing shall be rigidly supported on the turbine casing. Do not offer separate bearing.

Mechanical governor and operating levers shall be mounted on a fabricated steel extension in the turbine housing or bedplate. This assembly shall be sufficiently stiff to resist governor servo loads without appreciable deflection.

Supply turbine branch pipes and wye pipe as necessary. Use ASTM flanges on all turbine water pipes. Provide lifting eyes on turbine runner access cover and turbine housing.

TRANSFORMER SPECIFICATION

Distribution Class for use with Small Hydro Systems up to 500 kVa 3-phase, or 167 kVa single phase

Rating	
kVa	
Primary Voltage	
Secondary Voltage	
Phase	
Type	
Outdoor ONAN	
Indoor Dry Type	
Padmount	
Single Bushing Single Phase	
Two Bushing Single Phase	
Taps	
2 x 2 % above and 2 x 2 % rated voltage	
Dry Type Insulation	
Supply Class F or Class H	
Generator if Used	
Grounded Wye	
Ungrounded Delta	
Single Phase	

Standards	
Transformer shall conform to CSA standard C2 M1982, C9-M1 1981 or C227.2, 1974	
Surge Arrestor	
Supply Outdoor Surge Arrestor	
Supply Surge Arrestor on Dry Type Transformer	
Purpose	
(1) Step-up transformer connecting generator to transmission line	
(2) Step-down transformer connecting transmission line to load	
(3) Single phase transformer to be used on single phase system	
(4) Single phase transformer to be connected into 3-phase bank	

TYPICAL HOUSEHOLD APPLIANCE LOADS

Appliance	Power Watts	Average Hours Use/Mo.	Total Power Consumption kW./Mo.
Blender	600	3	2
Broiler	1436	6	8.5
Car Block Heater	450	300	135
Clock	2	820	1
Clothes Dryer	4600	19	87
Coffee Maker	600-900	12	7-11
Dishwasher	1200	25	30
Electric Blanket	200	80	16
Fan (Kitchen)	250	30	8
Frying Pan	1196	12	15
Hair Dryer (hand-held)	400	5	2
Hi-Fi (tube-type)	115	120	14
Hi-Fi (solid state)	30	120	4
Iron	1100	12	13
Kettle	1300	30	39
Light (60-watt)	60	120	7
Light (100-watt)	100	90	9
Lights (4 extra, 75-watt)	225	120	27
Light (fluorescent, 4')	50	240	12
Mixer	124	6	1
Radio (tube type)	80	120	10
Radio (solid state)	50	120	6
Refrigerator (standard 14 cu. ft.)	300	200	60
Refrigerator (frostfree 14 cu. ft.)	360	500	180
Sewing Machine	100	10	1
Sun Lamp	279	5.4	1.5
Toaster	1150	4	5
TV (black and white)	255	120	31
TV (colour)	350	120	42
Typewriter	30	15	0.45
Washing Machine	700	12	8
Water Heater (40-gallon)	4500	87	392
Water Pump	460	44	20
Vacuum Cleaner	750	10	8
Shop Equipment:			
Water Pump (1/4 hp)	460	44	20
Shop Drill (1/6 hp)	250	2	5
Skill Saw (1 hp)	1000	6	6
Table Saw (1 hp)	1000	4	4

TYPICAL LOADS FOR MAJOR APPLIANCES

Appliance	Average Watt	Monthly Average
Kitchen		
Dishwasher	1200	54
Fan	250	8
Kitchen Waste Disposer	375	2
Range - Apartment	1000	50
Range - S.F.D.	1000	100
Range - Self-clean	1000	83
Laundry		
Dryer	4600	75
Iron	1000	4
Washer - Automatic	350	5
Washer - Wringer	250	4
Washer - Twin Tub	300	12
Food Storage		
Freezer - Chest	340	119
Freezer - Upright	240	84
Freezer - Upright Frost-free	375	131
Refrigerator - Manual Defrost	400	60
Refrigerator - Freezer - Auto Defrost	800	120
Refrigerator - Freezer - Frost-free	900	135
Entertainment		
Hi-Fi or Stereo	150	11
Radio	50	4
Television - Colour	300	45
Television - Black and White	200	30
Water Heating		
Water Heater - Standard	3000	375
Water Heater - Cascade 40	6000	540
Water Heater - Cascade 60	6000	610

SIZING CHART FOR SMALL GENERATORS

	Appliance	Watts	Amps	Hours Per Month	kWh Per Month
1	Blanket	200	1.7	80	16
2	Coffee Pot	600	5.2	12	7
3	Kettle	1300	11.3	30	39
4	2 x 100W Lamp	200	1.7	90	18
5	2 x 75W Lamp	150	1.3	120	18
6	1 x 40W Lamp	50	0.4	240	12
7	Stereo	50	0.4	50	2.5
8	Vacuum Cleaner	630	5.5	1.2	0.8
9	Sewing Machine	100	0.86	10	1
10	Washing Machine	700	6	12	8
11	Car Block Heater	450	3.9	300	135
12	Skill Saw	1000	8.7	6	6
13	Electric Drill	250	2.1	2.2	0.1
14	Water Pump	460	4	44	20
15	Toaster	1150	10	10	11.5
	TOTALS	7290			295

Hours in One Month, Total = 720

Demand Factor = $\frac{295}{720}$ = 0.41

Demand Load, assuming Items 2,3,4,7,11,14 and 15 = 4.20 kW

Generator Capacity, Standard Size = 5 kW

4.38 VERY SMALL SYSTEMS - UNDER TWO KILOWATTS

For residential sized power systems, small or seasonal streams that cannot supply even 2kW continuously may contain enough energy to be worthwhile developing. If the stream's continuous power level is less than that required for certain appliances, water can be stored behind a small dam, or electrical energy can be stored in batteries.

With a dam, the water flow through the turbine will be controlled to meet the higher demands of larger loads. For smaller loads, water flow will be reduced. The system must be sized to take the maximum load: intake, penstock, turbine, generator, power lines must all be bigger than would be required for the average load.

Another way to operate loads that exceed the stream's continuous power level is to store the electrical energy in batteries during periods of lower demand. Thus the turbine and generator, and all other components can be smaller.

System Types

There are basically two types of very small systems:

Direct A.C. - where the power is use as it is generated. This is also the likely choice for systems over 2kW, or

Battery Storage - where power is stored during periods of low use in order to supply peak demands later. This is the likely choice for 1 kW or less. The DC power may be used directly or converted to AC.

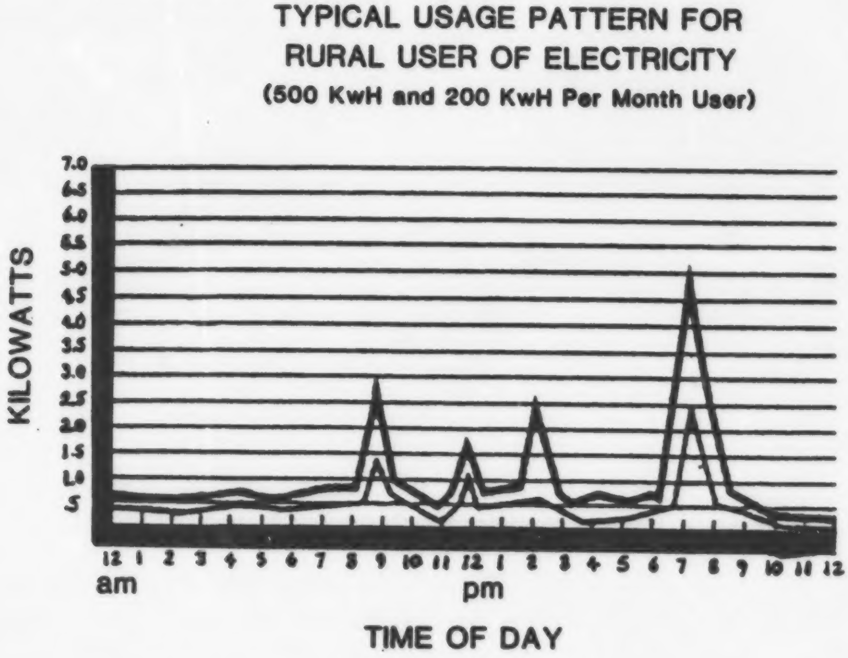

TYPICAL USAGE PATTERN FOR RURAL USER OF ELECTRICITY
(500 KwH and 200 KwH Per Month User)

Figure 4-149 Typical Electrical Use

The decision on which type to use has an overlapping grey area in the range of 1 to 2 kW wherein streaflow and loads should be evaluated specifically for each case. Recent developments in self-excited induction generation may also influence this decision. The choice may be easier with help from one of the consultants listed in the Handbook.

Electrical Needs

To appreciate the usefulness of battery storage, note that if 750 watts is generated continuously for the 720 hours in a month, this is the BC Hydro "average household" consumption of a home, not counting electrical heat or hot water. As little as 50 watts continuous generation can be useful for a cottage or cabin, as shown in Figure 4-149. This is typically the load size for which photovoltaic systems are used.

The electrical consumption usage should be estimated as accurately as possible since the estimate will affect all other system decisions. Chapter 1 and 3 outlined the method used for larger systems; a slight variation on that method is given here for convenience. For each load, or appliance, find the power use on the list in Figure 4-150, then enter on the worksheet, Figure 4-158, the average hours per month use (which may vary from the typical numbers given in column 2 of Figure 4-150). Don't just guess - it must be an accurate estimate. Either use the figures in column 2 or actually time the use, or meter the power at your present location. Try to keep in mind the worst case situation, for example, refrigeration loads in summer and lighting loads on long dark winter days. Note that refrigeration loads are likely to be the highest.

Then multiply each line on the worksheet to determine the monthly watt-hours of electricity needed. Total these, and add 25% to allow for battery and inverter losses.

Hydroelectric Potential

Make the head and flow measurements of the stream as described in Chapters 1 and 2. Use the PVC or polyethylene pipe friction listings from Figures 4-151 or 4-152 to determine the head loss. Subtract this loss from the total head measured to get the net head. Using this number, determine the continuouse power from the nomograph, Figure 4-153. Use the efficiency for your system: these values assume 50% system efficiency. Follow the worksheet calculations to obtain the monthly generating potential in kWh. Figure 4-157 is a worked example of the procedure.

In many instances, it will be obvious that there is abundant potential for electricity from the stream. If this is the case, choose a medium head, as this will tend to minimize both pipe costs and turbine speed problems, and select advantageous intake and turbine sites.

TYPICAL HOUSEHOLD APPLIANCE LOADS

Appliance	Power Watts	Avg. Hours Use/Mo.	Total Power Consumption KW Hr./Mo.
Blender	600	3	2
Car Block Heater	450	300	135
Clock	2	720	1
Clothes Dryer	4600	19	87
Coffee Maker	600-900	12	7-11
Electric Blanket	200	80	16
Fan Kitchen)	250	30	8
Freezer (Chest, 15 cu. ft.)	350	240	84
Hair Dryer (hand-held)	400	5	2
Hi-Fi (tube-type)	115	120	14
Hi-Fi (solid state)	30	120	4
Iron	1100	12	13
Light (60-watt)	60	120	7
Light (100 watt)	100	90	9
Lights (4 extra, 75-watt)	225	120	27
Light (flourescent, 4')	50	240	12
Mixer	124	6	1
Radio (tube type)	80	120	10
Radio (solid state)	50	120	6
Refrig. (standard, 14 cu. ft.)	300	200	60
Refrig. (frost free, 14 cu. ft.)	360	500	180
Sewing Machine	100	10	1
Toaster	1150	4	5
TV (black & white)	100	120	12
TV (color)	150	120	18
Washing Machine	700	12	8
Water Heater (40-gal)	4500	87	392
Vacuum Cleaner	750	10	8
Shop Equipment:			
Water Pump (½ hp)	460	44	20
Shop Drill (¼", 1/6 hp)	250	2	.5
Skill Saw (1 hp)	1000	6	6
Table Saw (1 hp)	1000	4	4
Lathe (½ hp)	460	2	1

Figure 4-150 Typical Appliance Loads

FRICTION LOSS - PVC CLASS 160 PSI PLASTIC PIPE

Pressure Loss from Friction in psi per 100' of Pipe
(Multiply psi by 2.3 to get feet of head)

Flow (gpm) US	Nominal Size						
	1"	1¼"	1½"	2"	2½"	3"	4"
1	0.02	0.01					
2	0.06	0.02	0.01				
3	0.14	0.04	0.02				
4	0.23	0.07	0.04	0.01			
5	0.35	0.11	0.05	0.02			
6	0.49	0.15	0.08	0.03	0.01		
7	0.66	0.20	0.10	0.03	0.01		
8	0.84	0.25	0.13	0.04	0.02		
9	1.05	0.31	0.16	0.05	0.02		
10	1.27	0.38	0.20	0.07	0.03	0.01	
11	1.52	0.45	0.23	0.08	0.03	0.01	
12	1.78	0.53	0.28	0.09	0.04	0.01	
14	2.37	0.71	0.37	0.12	0.05	0.02	
16	3.04	0.91	0.47	0.16	0.06	0.02	
18	3.78	1.13	0.58	0.20	0.08	0.03	
20	4.59	1.37	0.71	0.24	0.09	0.04	0.01
22	5.48	1.64	0.85	0.29	0.11	0.04	0.01
24	6.44	1.92	1.00	0.34	0.13	0.05	0.02
26	7.47	2.23	1.15	0.39	0.15	0.06	0.02
28	8.57	2.56	1.32	0.45	0.18	0.07	0.02
30	9.74	2.91	1.50	0.51	0.20	0.08	0.02
35		3.87	2.00	0.68	0.27	0.10	0.03
40		4.95	2.56	0.86	0.34	0.13	0.04
45		6.16	3.19	1.08	0.42	0.16	0.05
50		7.49	3.88	1.31	0.52	0.20	0.06
55		8.93	4.62	1.56	0.62	0.24	0.07
60		10.49	5.43	1.83	0.72	0.28	0.08
65			6.30	2.12	0.84	0.32	0.09
70			7.23	2.44	0.96	0.37	0.11
75			8.21	2.77	1.09	0.42	0.12
80			9.25	3.12	1.23	0.47	0.14
85			10.35	3.49	1.38	0.53	0.16
90				3.88	1.53	0.59	0.17
95				4.29	1.69	0.65	0.19
100				4.72	1.86	0.72	0.21
150				10.00	3.94	1.52	0.45
200					6.72	2.59	0.76
250					10.16	3.91	1.15
300						5.49	1.61
350						7.30	2.15
400						9.35	2.75
450							3.42
500							4.15
550							4.96
600							5.82
650							6.75
700							7.75
750							8.90

NOTE: Based on C=150

Dark underline = 5'/sec velocity

Figure 4-151 PVC Pipe Friction Loss

FRICTION LOSS - POLYETHYLENE (PE) SDR-PRESSURE RATED PIPE

Pressure Loss from Friction in psi per 100' of Pipe

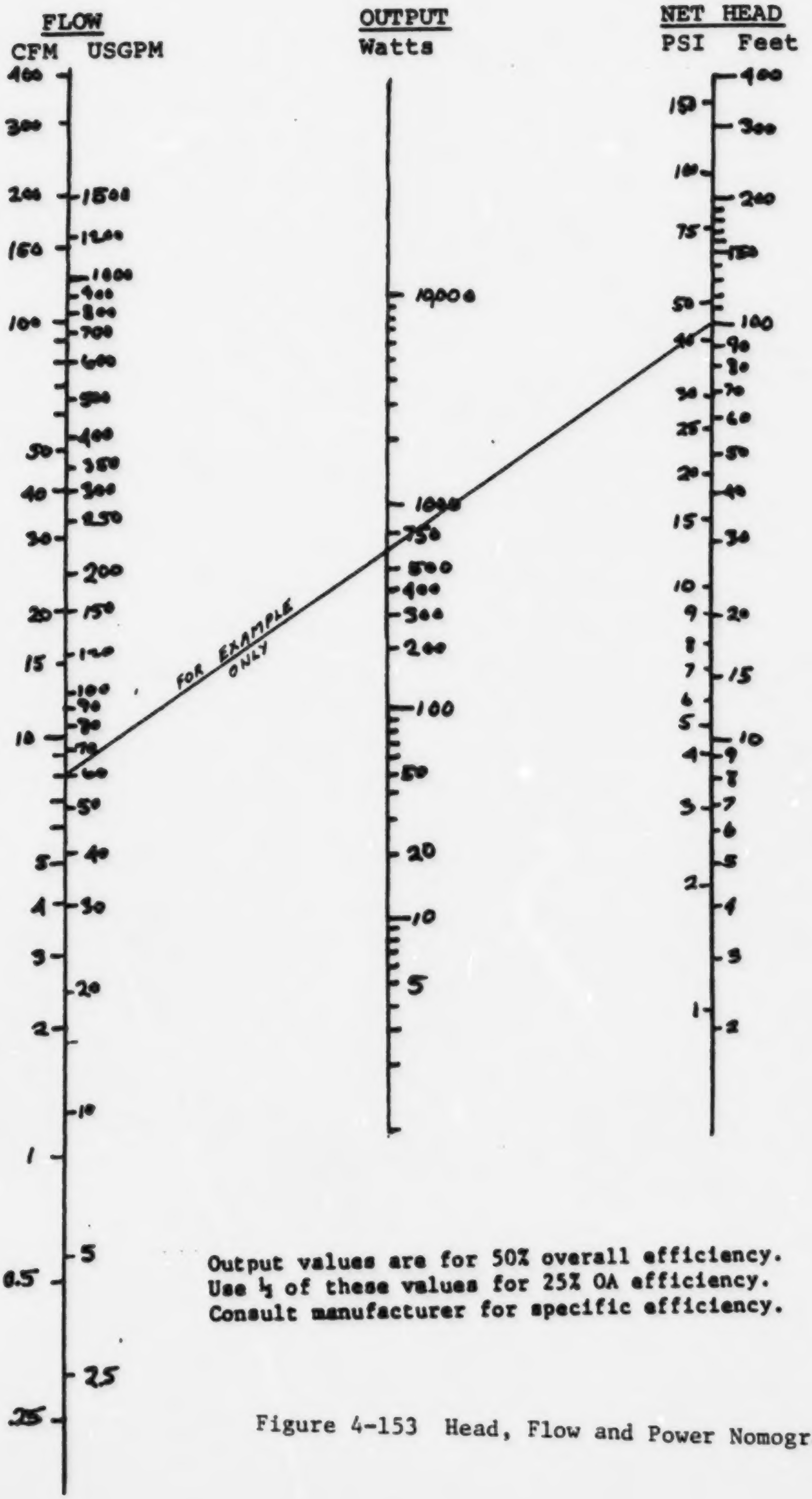
(Multiply psi by 2.3 to get feet of head)

Flow (gpm) US	Nominal Size							
	½"	3/4"	1"	1¼"	1½"	2"	2½"	3"
1	0.49	0.12	0.04	0.01				
2	1.76	0.45	0.14	0.04	0.02			
3	3.73	0.95	0.29	0.08	0.04	0.01		
4	6.35	1.62	0.50	0.13	0.06	0.02		
5	9.60	2.44	0.76	0.20	0.09	0.03		
6	13.46	3.43	1.06	0.28	0.13	0.04	0.02	
7	17.91	4.56	1.41	0.37	0.18	0.05	0.02	
8	22.93	5.84	1.80	0.47	0.22	0.07	0.03	
9		7.26	2.24	0.59	0.28	0.08	0.03	
10		8.82	2.73	0.72	0.34	0.10	0.04	0.01
12		12.37	3.82	1.01	0.48	0.14	0.06	0.02
14		16.46	5.08	1.34	0.63	0.19	0.08	0.03
16			6.51	1.71	0.81	0.24	0.10	0.04
18			8.10	2.13	1.01	0.30	0.13	0.04
20			9.84	2.59	1.22	0.36	0.15	0.05
22			11.74	3.09	1.46	0.43	0.18	0.06
24			13.79	3.63	1.72	0.51	0.21	0.07
26			16.00	4.21	1.99	0.59	0.25	0.09
28				4.83	2.28	0.68	0.29	0.10
30				5.49	2.59	0.77	0.32	0.11
35				7.31	3.45	1.02	0.43	0.15
40				9.36	4.42	1.31	0.55	0.19
45				11.64	5.50	1.63	0.69	0.24
50				14.14	6.68	1.98	0.83	0.29
55					7.97	2.36	0.99	0.35
60					9.36	2.78	1.17	0.41
65					10.36	3.22	1.36	0.47
70					12.46	3.69	1.56	0.54
75					14.16	4.20	1.77	0.61
80						4.73	1.99	0.69
85						5.29	2.23	0.77
90						5.88	2.48	0.86
95						6.50	2.74	0.95
100						7.15	3.0	1.05
150						15.15	6.36	2.22
200							10.87	3.78
300								8.01

NOTE: Based on C = 140 **Dark underline = 5'/sec velocity**

Figure 4-152 Polyethylene Pipe Friction Loss

HEAD - FLOW - OUTPUT NOMOGRAPH



Output values are for 50% overall efficiency.
Use ½ of these values for 25% OA efficiency.
Consult manufacturer for specific efficiency.

Figure 4-153 Head, Flow and Power Nomograph

If there is insufficient hydro-electric potential:

- try to get more head by going further upstream with the intake, or downstream with the turbine;
- reduce your electrical needs - compact fluorescent lamps use 9 watts instead of 60 watts, and efficient appliances can help;
- consider backing up the system with an engine-generator, solar electric, wind power, etc.

Civil Works and Equipment

Because batteries are being charged to store power for peak needs, the intake, penstock, powerhouse, turbine-generator and transmission lines need only handle the average power, not the peak. This results in smaller components, reduced cost and simpler construction. For example:

- Stream diversions and intake can be elementary in design compared to the larger systems described.
- Penstock piping can be small diameter PVC or polyethylene. The domestic water line or an irrigation system may have sufficient head and flow to produce useful power. This is almost certainly true for a cottage or cabin.
- The powerhouse can be just basic weather protection for the generator; a walk-in building is not necessary. The batteries and inverter (if used) should, however, be indoors for cold-weather and moisture protection.
- Small, inexpensive turbine-generator units are available in a variety of types: low-head to high-head, some using pumps running backwards, plastic turgo wheels, and bronze peltons. Some use automotive alternators which while inexpensive, are not very efficient. Permanent-magnet generators need no power for field excitation, and are generally of higher quality, therefore considerably more efficient. Some types are brushless. AC output allows greater voltage flexibility for transmission and the battery bank configuration.

Overall efficiency of these inexpensive turbine-generator units varies greatly, from 25% to 50%. It is important to consult the manufacturer or distributor. The efficiency must be taken in to account when using the nomograph to determine useful power output. Larger, direct AC systems have higher efficiencies: from 60% to 75%.

Figure 4-154 shows the turbine speed as a function of the load. When the load is lost suddenly, runaway speed can be quickly reached, and is in the order of 50% more than the design speed. Do not forget to consider this overspeed condition and the possible effects of it should the load be lost for any reason.

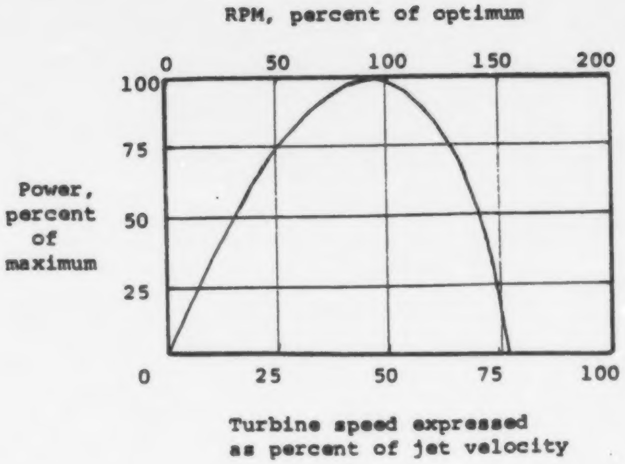


Figure 4-154 Turbine Speed vs. Load

One way to utilize a very small hydro plant is to power a constant, dedicated load, such as water or building heat, to use the power effectively whenever it is being generated. Power regulation would be simple in that case. The other way to fully use the power is to store the electricity in batteries.

Batteries

Only lead-acid batteries are cost-effective at the present time. Deep cycle types with thick, antimony alloy grids give longer service per dollar. Examples are "motive power cells"; batteries used in golf carts and fork lifts. Stationary batteries with the same charge-discharge characterisitics are also suitable.

Battery voltage is largely determined by peak loads, because larger inverters require higher DC input voltage. The common DC voltages are 12, 24, 36, and 48 volts. Without an inverter, 12 V DC or 110 V DC can be directly used.

The required battery capacity for hydro systems is much less than for solar electric, wind or generator systems, because power is being generated 24 hours per day, year round. This continuouse input means battery discharges are much shallower, extending their life.

Battery sizing:

- Must be large enough to maintain the minimum input voltage to the inverter during surges and peak loads.
- Total capacity equal to 1.5 times the average daily load should be considered to be the minimum.

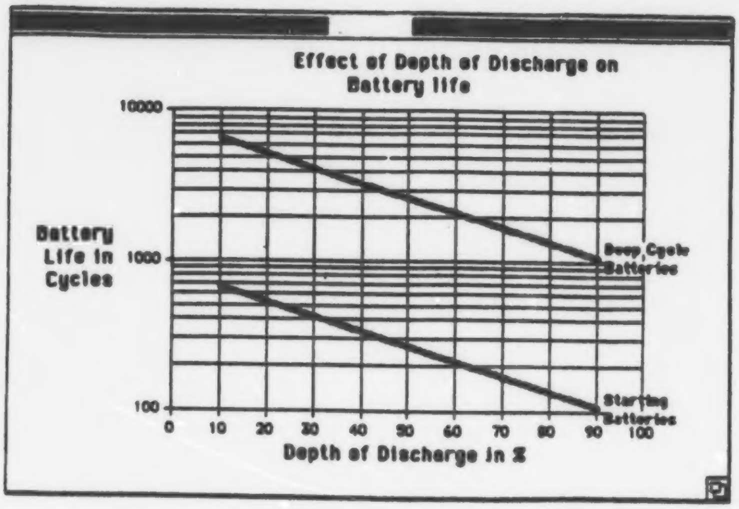


Figure 4-155 Effect of Discharge Depth on Battery Life

Battery life is extremely dependent on proper charging and maintenance. Figure 4-155 shows the effect of discharge depth on battery lifetime.

Another advantage to battery storage is being able to maintain power during maintenance or repairs on the small hydro system. If necessary, batteries can be recharged periodically with a standby engine-generator to maintain 24 hour per day power.

Regulation and Controls

For a direct AC system, frequency-sensing load control governors are available to keep the generator speed steady to provide constant 60 Hz power. Voltage regulation is a separate function from frequency regulation.

For battery systems, the ability of the relatively large battery storage to accept significant amounts of electricity in a narrow voltage range eliminates the need for voltage regulation at the generator. In fact, permanent-magnet genertors cannot be voltage regulated. Voltage output is a function of generator speed, and turbine speed. Any head changes will therefore affect the output voltage of that system.

Where a regulatable generator is being used, the automotive method of voltage control would not be good for a hydroelectric situation, since the load is reduced, allowing the speed to increase, which then requires further regulation.

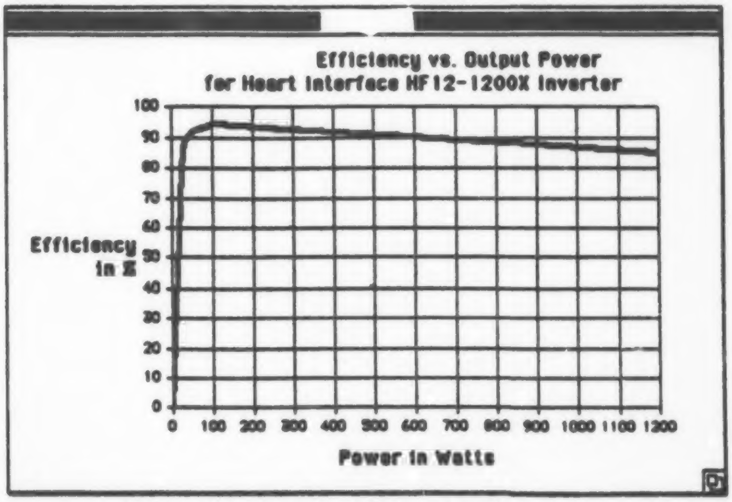
Other complications are, from Figure 4-154:

- high speed will shorten the bearing life and increased splash may be a problem.
- Reduced generator load will lower the operating temperature; moisture and condensation may be more likely, and bearings operate better at moderate temperatures.

A better way to prevent battery overcharging is to divert electricity to as useful a load as possible, but one which is always available. Load and speed on the generator are then maintained and the above problems are avoided. Power diversion is accomplished by controlling a relay with two voltage sensitive set points, which are responsive to battery voltage. The relay contacts are closed to the dump load when the battery voltage is high (charged) and opened when the falling voltage indicates that system loads are on.

Inverters

The modern solid state inverter allows operation of all common AC appliances and tools from a DC source of power. Recent developments in electronics and a demand in the alternative energy market make this the most rapidly changing technology area in very small hydro



(Less than 1 watt idling loss)

Figure 4-156 Efficiency vs. Power Output

systems. Depreciation is therefore very high, because next year's models will be significantly better and/or cheaper. Make every effort to buy the right one the first time. Comparisons are difficult because there are not yet any performance standards. Figure 4-156 shows how one manufacturer maintains high efficiency, even at low power output. Talk to several suppliers and to other very small system owners regarding their experience and recommendations.

Modern inverter strong points are:

- good efficiency over a wide load range.
- standby losses (idling power draw) are negligible.
- No moving parts.

Weak points are:

- difficulty in providing the peak power (surge) required to start AC induction motors, such as fridges, skill-saws, etc.
- they are expensive.
- the high complexity has tended toward low reliability.

The system's maximum surge load and maximum continuous load are limited mainly by the inverter size. Small compromises in energy use and convenience can reduce these peaks and allow significant cost savings due to the smaller required inverter size. For example, cooking with propane or wood instead of electricity will greatly reduce the peak load. This load management was previously described in detail.

Legal Aspects

For your own protection, always apply to the Water Management Branch for a licence to use water, before starting construction. On heavily used streams with other licenced users, battery systems will have lower water flow requirements, and may enable you to get a licence that would otherwise not be available.

EXAMPLE ONLY

WORKSHEET - Under 2KW

Appliance/equipment	Power watts	Usage Hours/ mon	Energy Watt-hrs/mon
REFRIGERATOR	300	200	60,000
FREEZER	350	240	84,000
AUTO WASHER	700	12	8,400
VACUUM CLEANER	750	10	7,500
FLUORESCENT LIGHT 4'	50	180	9,000
4 - 60 WATT LIGHT	240	180	43,200
MISC. APPLIANCES			20,000
MISC. TOOLS			20,000

sub-total 252,100
+ 25% losses 63,025
Total 315,125
divided by 1000 = 315 KwH/mon Load

Flow = 60 USGPM or CFM

Pipe dia 2" has friction loss 4.2 ft/100' X total pipe length $\frac{800}{100}$ ft = 34 ft total pipe head loss

Measured head 135 ft LESS total pipe head loss 34 ft = 101 ft Net Head

Nomograph output $\frac{625}{1000}$ watts X your OA eff. $\frac{40}{50}$ % X 720 hrs/mon = 360 KwH/mon generating potential

Monthly load 315 KwH DIVIDED BY 30 days/mon X 1½ = 16 KwH minimum batt. capacity

Battery capacity 16 KwH 1000 DIVIDED BY 24 system voltage = 667 amp-hrs battery capacity

Figure 4-157 Example Worksheet

WORKSHEET - Under 2KW

Appliance/equipment	Power watts	Usage Hours/ mon	Energy Watt-hrs/mon

sub-total ________
+ 25% losses ________
Total ________
divided by 1000 = ____ KwH/mon Load

Flow = ____ USGPM or CFM

Pipe dia __" has friction loss ___ ft/100' X total pipe length $\frac{\_\_\_\_}{100}$ ft = ___ ft head loss

Measured head ____ ft LESS total pipe head loss ___ ft = ____ ft Net Head

Nomograph output $\frac{\_\_\_\_}{1000}$ watts X your OA eff. $\frac{\_\_\_}{50}$% X 720 hrs/mon = ____ KwH/mon generating potential

Monthly load _____ KwH DIVIDED BY 30 days/mon X 1½ = ____ KwH minimum batt. capacity

Battery capacity ____ KwH 1000 DIVIDED BY ___ system voltage = _____ amp-hrs battery capacity

Figure 4-158 Worksheet

VERY SMALL SYSTEMS CASE STUDIES

Three examples of very small systems are given to show the nature and variety of solutions which enterprising developers have used to provide power. Two are battery systems, the other is a self-excited induction generator.

1. Mackenzie - 210 watts

Located 8 km from Tyaughton Lake (Tyax Lake) near Goldbridge, B.C. this system combines a domestic water supply with a small power system using high voltage (110 volts) DC and batteries.

Summary

Completed:	1985
Capacity:	210 watts (approx. 30% overall efficiency)
Gross Head:	230 feet
Penstock:	2 inch dia. PVC Class 160, 1700 feet long, buried 4 ft., installed for domestic water supply
Turbine-generator:	4 inch dia. polyurethane Turgo runner, direct drive to permanent magnet 3 phase AC generator (unit by Energy Systems and Design)
Flow:	18 USgpm, (.04 cfs) with single 1/4 inch dia. nozzle, water source is a spring at elev. 3500 ft.
Transmission:	200 feet, No. 6 AWG aluminum, 3 conductor wire
Battery:	108 volts DC nominal (nine 12 V batteries, 90 amphour , Varta RV type
Regulation:	Diversion of electricity to dump load (light bulbs) at 132 volts
Loads:	Automatic clothes washer modified for operation at 110V DC, lights, table saw, small power tools, brooder lamp

		Approx.
Project Costs:	Turbine-generator	$ 500
	Transmission line conductor	scrap
	Battery bank	675
	Regulation	75
	Modification of washer to 110 V DC	300
	Motor for table saw, 110 V DC	120
	TOTAL	$1670

2. Scheiber - 500 watts

Located on the coast, near Powell River, this system also uses batteries. The original 24 volt single phase synchronous generator has recently been replaced with a stand-alone induction generator. It operates at 200 Volts AC and is stepped down and rectified to DC for charging the batteries.

The original project used a syphon intake using steel pipe with rubber gaskets. However, the gaskets leaked and the syphon frequently failed. After three years of unsatisfactory operation, the need for a syphon was eliminated by extending the pipe further upstream; 150 feet of PVC pipe was added for a gain of only 5 feet in gross head.

The advantage of using and induction generator is that a relatively inexpensive off-the-shelf induction motor could be used, which is brushless, has no rotating windings and is widely available. The excitation current is supplied by capacitors connected across each phase of the output lines.

Summary

Completed:	Initial system in 1985, induction generator - 1988
Capacity:	500 watts (approx. 30% overall efficiency)
Gross Head:	50 feet
Penstock:	180 feet of 6 inch dia. steel pipe (used), 150 feet of 6 inch dia. PVC pipe, not buried
Turbine-generator:	4 inch dia. polyurethane Turgo runner, direct drive to 3 phase, 200 V, AC induction generator
Flow:	225 USgpm (0.5 cfs) with two 0.9 inch nozzles
Transformer:	3/200 VA transformers (one per phase) 200/24 volts, recitified to 24 V DC
Transmission:	600 feet of 1/0 aluminum, 2 conductors (for original 24 V DC system) plus single strand No. 12 copper
Battery:	24 V, 360 amp hour
Regualtion:	Diversion to load dump (heater) at 29 V DC
Inverter:	24 volt input, 2500 watt continuous
Loads:	Refrigerator, chest frezzer, clothes washer, vacuum cleaner, small appliances, lights, stereo, small power tools

		Approx.
Project Costs:	Penstock	$ 300
	Turbine-generator	850
	Transformers (surplus cost)	100
	Transmission line (scrap cost Alu. plus copper)	140
	Battery bank	600
	Regulator	75
	Inverter	2800
	TOTAL	$ 4865

3. Hall - 1500 watts

Located near Cranbrook, this was the first stand-alone AC induction generator to be installed. It uses electronic control and excitation equipment recently developed by Thomson and Howe Energy Systems. Usually, synchronous generators have been use for stand-alone generators. Now, Less expensive and more easily available induction motors can be used for small generators.

Summary

Completed: 1989
Capacity: 1500 watts max., fun at 700 - 1000 watts
Head: 110 ft. gross head; 77 ft net with two .9 in. nozzles
Flow: max. 225 USgpm; 100 USgpm with two .9 in. nozzles
Turbine-generator: 4 in. pulyurethane Turgo runner, direct drive to 575V 7.5 hp, 3 phase induction motor (used), 1800 rpm; modified to generate single phase 480 V AC
Transmission: 500 feet, 12 ga. 500 V, 2 conductors in 3/4 in. dia. buried plastic pipe (to house)
Transformer: 3 KVA dry transformer, 480 - 120/240
Controls: Induction excitation by modified "JV" governor by Thomson and Howe, provides voltage and frquency control. Not suitable for starting larger induction motors (fridge)
Loads: Lights, small appliances, computer, stereo, small power tools
Auxiliary power: 4 kW gasoline generator for loads such as saw, washer

		Approx.
Project Costs:	Penstock	$ 1200
	Turbine-generator	850
	Transmission line	250
	Transformer	270
	Controller	900
	TOTAL	$3470

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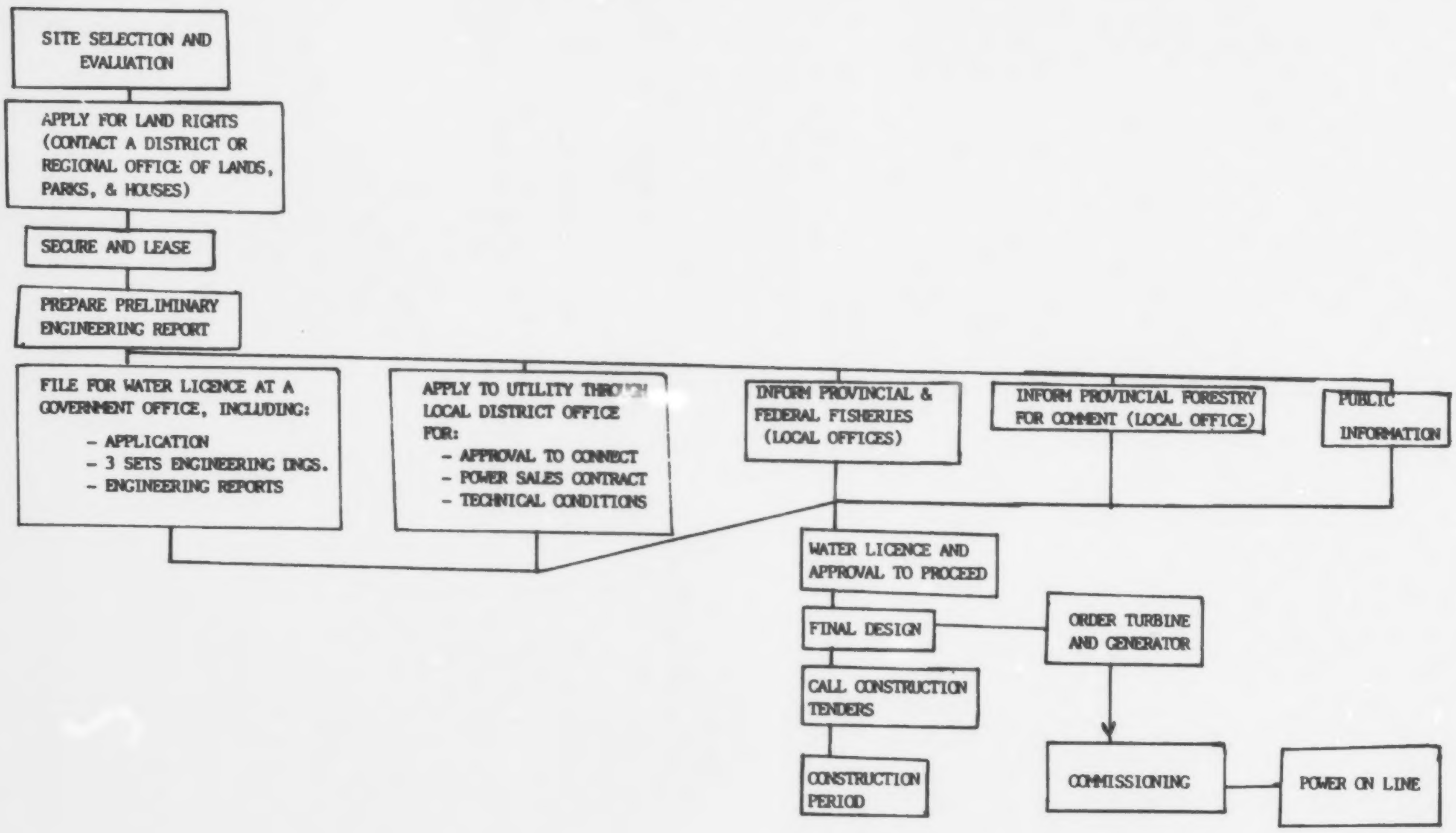
HOW TO USE CHAPTER 5

This is a complex subject, and this chapter presents it in considerable detail.

Most small hydro developers will actually use very litte of this chapter, because their requirements will be straightforward, and limited to a water license. In that case, you can ignore, or better, merely skim, large sections of this chapter.

To find your way through this chapter without getting bogged down in unnecessary detail, we suggest that you read 5.1 (introduction), 5.1.1 (agency involvement), glance at 5.1.2 (qualifying as a utility), and review the approvals checklist (5.1.3) carefully. You will be able to judge which items in the approvals checklist are likely to be important to you - and them follow up on these specific items in the section that follows.

It is also worthwhile to consider the recommendations (5.5) in your first perusal of this chapter - since these are quite specific, and will further assist you in zeroing in on the subjects that are important to your project, and leaving the others to one side.


SITE SELECTION AND EVALUATION
APPLY FOR LAND RIGHTS (CONTACT A DISTRICT OR REGIONAL OFFICE OF LANDS, PARKS, & HOUSES)
SECURE AND LEASE
PREPARE PRELIMINARY ENGINEERING REPORT
FILE FOR WATER LICENCE AT A GOVERNMENT OFFICE, INCLUDING:
- APPLICATION
- 3 SETS ENGINEERING DWGS.
- ENGINEERING REPORTS
APPLY TO UTILITY THROUGH LOCAL DISTRICT OFFICE FOR:
- APPROVAL TO CONNECT
- POWER SALES CONTRACT
- TECHNICAL CONDITIONS
INFORM PROVINCIAL & FEDERAL FISHERIES (LOCAL OFFICES)
INFORM PROVINCIAL FORESTRY FOR COMMENT (LOCAL OFFICE)
PUBLIC INFORMATION
WATER LICENCE AND APPROVAL TO PROCEED
FINAL DESIGN
ORDER TURBINE AND GENERATOR
CALL CONSTRUCTION TENDERS
CONSTRUCTION PERIOD
COMMISSIONING
POWER ON LINE

IMPLEMENTATION OF A SMALL HYDRO POWER PROJECT

FIGURE #1

5 PERMITS, LICENCES AND LEGAL ASPECTS FOR SMALL HYDRO

5.1 INTRODUCTION

This section is intended to serve as a guide in your efforts to satisfy the local, provincial and federal approval requirements for constructing and operating a small hydro power plant in British Columbia.

Items to be discussed include:

(a) an approval, permit and licence checklist;

(b) equipment and liability insurance coverage;

(c) the local, provincial and federal approvals, permits and licences important to a developer;

(d) the important legal aspects such as offences, fees and rentals, and expropriation powers;

(e) the information required by potential referral and review agencies, and the conditions or obligations they may impose on a development;

(f) the important procedures necessary to obtain an approval, permit or licence; and

(g) final recommendations.

5.1.1 Agency Involvement

Permitting and licensing requirements can include a wide variety of issues such as legal compliance, public safety, and environmental concenrs. How such requirements fit into the engineering and technical aspects of a hydropower investigation are shown in Figure 1.

A key component for successful development involves an awareness of the existing institutional and legal regulations, and may require interaction with various agencies and levels of government. Understanding the required approvals can save both time and money.

Numerous agencies and entities have potential permitting or review authority. In some cases, filing for permits and licenses can require considerable time and extend over a substantial part of the development and construction period. Run-of-river projects and those located exclusively on private lands may not require all possible permits and reviews.

In spite of the time, costs and effort spent to obtain approvals, the process benefits the developer because it focusses attention early in the planning phase onto problems that may have arisen later.

It's best to push efforts on several fronts at the same time, for the following reasons:

(a) to reduce potential delays;

(b) to reduce the personal time, cost and effort spent waiting to receive approvals, permits and licences;

(c) to understand who and why to contact, should problems or delays arise with the permit or license applications at a later date;

(d) to understand to whom, where and why application forms are being referred, or who is reviewing them, so that discussions can begin early with the specific agency or agencies; and

(e) to understand what information certain agencies will require, so that you can incorporate specific elements into the feasibility study, within the actual development, and, of course, so you can give everything needed on the application forms.

5.1.2 Qualifying as a Utility

The British Columbia Utilities Commission Act, SBC, 1980, c.60, as amended, establishes the B.C. Utilities Commission as the body responsible for regulating public utilities. Regulated projects are defined according to the amount of energy used or involved in production or transmission.

Electrical projects exceeding 20 MW would be considered a large enough project to be regulated by the Commission. A regulated project may be required to obtain certificates of operation and construction, issued by the Ministry of Energy, Mines and Petroleum Resources prior to operation.

Projects having a capacity of less than 20 MW are within the streamlined application and approval process set by the Commission, and generally not defined or regulated as a public utility.

If you produce a power service primarily for your own requirements you cannot sell surplus power except a) to your employees or tenants; (b) by permission of Ministerial order or, (c) by authorization from the Commission, where authorized by The Minister (s. 27).

If you are contemplating the production of power for distribution to communities or private individuals of generally 50 buildings or more, discussion with the Commission would help determine if public utility regulation is required or necessary. In most cases, local surplus power distribution on a small scale would not warrant full Commission involvement, but the Commission should be made aware of the situation through written or telephone contact.

5.1.3 Approvals Checklist

1. A provincial water licence is required to legally divert (or take) surface water from the stream or river. This also applies to private lands. (Contact: Ministry of Environment, Water Rights Section.)

2. If dams or diversions are to be constructed or operated, the design and construction plans must be reviewed and approved prior to construction. (Contact: Ministry of Environment, Water Rights Section.)

3. Before constructing any works, you should get the permission of every property owner whose land the works will cross or affect. Verbal agreements are not binding and all agreements should be detailed in writing. (Contact: Land Titles Registry Offices.)

4. If the sale or supply of surplus power to individuals, communities or industries is planned, approval by the British Columbia Utilities Commission may be required. (Contact: British Columbia Utilities Commission.)

5. Electrical installations require a permit. Installations for a single family dwelling can be done by the homeowner; in all other cases, installations must be done by electrical contractors holding approved certification. All equipment and machinery should be approved prior to installation. (Contact: Ministry of Labour, Electrical Safety Branch.)

6. Insurance coverage should be arranged for all works during and after construction; and comprehensive general liability insurance should be retained if you are is selling or supplying power to individuals, communities or industry. (Contact: Insurance Agents or Brokers.)

7. For works located within municipal boundaries, unorganized territory, or regional districts, you should contact the local offices for information on any zoning and by-law compliances, and for building permits where required. (Contact: Municipal and Regional District Offices.)

8. If the works (penstocks, transmission lines) cross Crown land a permit to authorize occupation can be obtained by formal application. (Contact: Ministry of Environment.)

9. If the work cross substantial Crown lands; involve right-of-ways, flooding of lands, or timber cutting; and require long term tenure, licences for occupation can be obtained by formal application. (Contact: Ministry of Lands, Parks and Housing.)

10. If the works are to be located within a provincial park, a permit to authorize plant construction or water withdrawals can

be obtained by formal application. (Contact: Ministry of Lands, Parks and Housing.)

11. If the works are to be located within provincial forest areas, tree farm licence or supply areas, or on lands other than private holdings, a licence or special use permit to authorize timber cutting and removal can be obtained by formal application. (Contact: Ministry of Forests.)

12. If roadways or driveways required for access to the works join provincial highways, or other secondary roads, they require approvals prior to connection. (Contact: Ministry of Highways.)

13. Water licence and Crown land applications are referred to other government agencies. Legally binding conditions and obligations can become part of the issued water or Crownland licence. Agencies may impose construction, operation and environmental obligations that include fish ladders, regulated flows and land reclamation. (Contact: Various government agencies - Fish and Wildlife, Forestry.)

14. If the works are located within Federal lands (Native Reserves, National Parks), approvals for construction and water withdrawal or diversion can be obtained by formal application. (Contact: Indian and Northern Affairs, Parks Canada.)

15. All water licence applications are referred to the federal Department of Fisheries, which can impose strict environmental protection requirements and mitigative measures that include fish ladders or regulated flow discharges. (Contact: Department of Fisheries and Oceans.)

16. If the works are located on navigable or international rivers or streams, various federal approvals may be required. (Contact: Department of Transport.)

* See either the local, provincial or federal sections for greater detail and explanation on required approvals.

5.1.4 Liability Insurance

Insurance coverage for a small hydro project involves two basic types of coverage. The first is standard insurance on the physical works (pelton wheels, turbine, generating equipment), against natural perils and risks, breakdown of equipment, or theft and vandalism. The insurance rate is usually based on the value of the equipment or structures. Insurance coverage is considered a standard precaution when investing in expensive equipment, and is analogous to normal house or automobile insurance coverage.

The second type of insurances known as comprehensive general liability insurance protects you as hydro power supplier, from lawsuit or complaint in the event of non performance of duties, accidents or mishaps when supplying or selling power to customers. If you are connecting to the existing utility grid, evidence of sufficient developer insurance coverage is required by the utility before any contractual negotiations are finalized.

If utility sale contracts are negotiated, the protection you have for indemnity from the utility, and the protection the utility has for indemnity from you must be defined.

If you are thinking of either selling or supplying power to properties in addition to your own, you should seek professional advice on liability insurance packages.

To obtain insurance of either type, contact an insurance agent or broker, and provide him or her with a clear understanding of all aspects of the proposed or developed project. The agent or broker will assess the overall project risks, and research your financial situation, the expected gross receipts of the proposed utility, the anticipated quantity and market for the power sales, and any other risks or uncertainties applicable to the project. The assessment process could involve site inspections by the insurance agent.

Once the agent is satisfied of the viability of both you and your project, he or she goes to the market to convince an insurance company to underwrite the insurance policy the utility. The insurance company assesses the project and then either accepts or rejects the proposal. If the proposal is accepted, the insurance company determines and sets the appropriate annual insurance rates.

Insurance rates may be quoted on per thousand dollars of power sales, gross receipts of the utility, or kilowatt output. This will vary, depending on the company. You are expected to pay regular fixed charges to maintain the existence of the issued insurance policy.

You might be tempted to sell or supply power without insurance. This is unwise. In the event of damage, loss of life or limb, or loss of business opportunity on the part of the customer, you can be held negligent and punishable for damages within a court of law. Do not assume that standard homeowners' insurance policies will cover the selling or supplying of power from a commercially operating small hydro plant.

Additional insurance coverage might include worker's compensation, and employee or construction insurance during the plant construction phase, in order to protect you and your investment against accidents and complaint.

5.2 LOCAL INVOLVEMENT

You should make contact with local Municipal and Regional District offices early in the project study. Local officials may require only a cursory review of the proposed development plans, and comment on relevant zoning or by-law regulations, or issue building or construction permits.

> Frank discussion at the local level should assist you by, indicating any further local approvals or authorization required; allowing for input and expertise into the proposed project from officials familiar with the area, and alerting you to further provincial or federal approval requirements.

Getting the local permits and licences that you need should not take more than two or three months.

5.2.1 Legislation

The Municipal Act RSBC 1979, c.290, as amended, sets out the powers and duties of municipal governments within the province. The governing body of a municipality is the Municipal Council, which is the key authority controlling land use within the municipality. The ACt gives the council power to annually tax local electric companies (s.407), to enact zoning by-laws (s. 702) and establish building regulations (s.734).

Local government have complete control of municipally owned lands and can closely regulate any development on such property. By-laws allow local governments to exercise land use powers. The Act empowers regional districts to impose zoning regulations with respect to the unorganized territory of their district.

Zoning

The zoning provisions give municipal councils the power to regulate use and prohibit any use in any municipal zone or regional district (s. 716 (1) (b). As a result, zoning by-laws generally list the permissible uses for each zone. Such by-laws could affect you, as a small hydropower developer, by restricting the land use development for which the hydro plant is to supply power: for example, a proposed sawmill utilizing small hydropower in a non-industrial zone, or a private company attempting to sell surplus hydroelectric power in a non-commercial zone. Courts will not allow a municipality to prohibit all uses of privately owned land.

A private landowner can initiate a change in the existing zoning designation, by applying to Council to have his property re-zoned. The Act authorizes Council to impose fees with respect to such applications. The Act gives council power to regulate the "size, shale and siting" of buildings and structures according to each zone (s. 716(1)(c).

Structures

Building permits are issued for the construction of buildings that conform to zoning and other by-laws. Under the Act a Council can only regulate building construction and alteration (s. 734 (a).

The legislation governing the building permit is brief. The Act authorizes Council to require by by-law, owners or contractors to

> obtain a valid permit from the Council or authorized officials before beginning construction or alteration of any buildings or structures (s. 734(e)).

Before any building construction may begin, you must submit your plans to a municipal building inspector, who will issue a building permit only if the local regulations are obeyed. Under the Act, the municipal Council must consider the building permit application within thirty (30) days of the received application (s. 724(2)). You must demonstrate that the project conforms to local by-laws.

The Regional Board has the powers of a municipal Council regarding building permits in unorganized areas of the regional district (s. 818).

The Act gives Council the power to regulate the installation of plumbing, heating, gas and oil and other services in buildings (s 734(b)). Council further utilizes regulations are made under the Electrical Safety Act, RSBC, 1979, c. 104, as amended and published by the Electrical Safety Branch. A local by-law that is inconsistent with the code or regulations made by the Minister is of no force and effect (s. 740(3)). A municipality or regional district can adopt additional safety requirements if deemed necessary.

By-laws

The Municipal Act gives the municipal councils and regional boards the power through by-laws to;

> ...prohibit a person from fouling, obstructing, or impeding the flow of any stream, creek, waterway, or watercourse... whether or not it is situated on private property, and may provide for the imposition of penalties for any contravention of such regulations (s. 587(a))."

The Act provides that any person who obstructs or injures any ditch or watercourse constructed or improved under the provisions of the Act is liable to do such restoration as the Court directs and is liable to a penalty not exceeding $200 (s. 593). Powers exercisable under the above sections are subject to the provincial Water Act, RSBC 1979, c. 429, as amended.

The Act provides for the establishment and use within or outside the municipality of plants to supply electrical energy. The construction, charges and rates, and extension of supply of electrical energy systems may be regulated by the municipal and regional district authorities (SS. 635, 636, and 642).

You will have to comply with local by-laws involving car park facilities, site safety, land drainage, sewage, lighting and water main hook-up provisions. Early discussion with authorities can help you incorporate local design and safety requirements into your final plant construction plans.

5.2.2 Approvals, Permits and Licences

You will require:

(a) local by-law and zoning approvals;

(b) electrical or plumbing safety code approvals;

(c) building or structure permits.

5.3 PROVINCIAL INVOLVEMENT

The provincial government approval requirements include: water rights; dam safety compliance; electrical safety; crown land licence or lease; and, additional referrals and environmental considerations.

When you apply for a water licence, your application will automatically be referred to other agencies for comment and approval. All water licence applications are reviewed by the Ministries of Agriculture; Fish and Wildlife; Lands, Parks and Housing; the Federal Department of Fisheries; and B.C. Hydro. These reviews may lead to cancellation, delays, specific design and technical requirements, and public notice or review. You should understand the potential approvals and referrals, as you plan the most cost effective and efficient approach to your project.

The time required to receive provincial approvals, permits or licences varies from agency to agency, and will depend on the complexity of the proposed development. Be prepared for approvals to take a year or 18 months: they can take longer, although this is unusual.

Most agencies try to respond within 30 days of receiving the referred water licence application, but this depends on their current work load.

On site inspections by the agencies involved will probably be necessary. Early contact with the specific agency can ensure an appropriate time for you and the agency representative to inspect the site.

5.3.1 Water Rights

All small hydro developers need a water licence. Obtaining a licence involves agency contact, application filing, referral agency reviews, on-site inspections, fees and rentals, and maintenance of added environmental protection measures. The water licence application process can exceed 12 months, depending on such factors as site constraints, plant design, and the quality of information supplied by the developer.

Legislation

Water is a Crown owned resource, managed by the Ministry of Environment. The Water Act RSBC, 1979, c. 429, as amended, is the main provincial statute regulating the use and development of water resources in rivers and streams in the province.

As defined by the Act it is illegal to take surface water from a stream without first obtaining a water licence or an approval (except for firefighting, or unrecorded water used for domestic or prospecting purposes).

The water resource is allocated and its use is regulated under a licensing system that ensures that existing rights on the resource are respected. For example, your neighbour may have a right to a minimum flow and you won't be allowed to take water if your doing so interferes with his rights. A water licence is issued by the Comptroller of Water Rights, or one of the Regional Water Managers, appointed under the Act, and both may authorize the diversion, storage or other alterations of a stream or lake, and the structural integrity of dams and other works, to ensure public safety.

Other circumstances requiring control include: the draw down of reservoirs for the closure of power plants and the repair of dams; and the release of stored water to enhance navigation or to control flows for fisheries purposes. Regulation required for dam safety purposes is part of the dam safety program under the general Flood Damage Prevention activity.

As defined by the Act, "power purposes include the use of water in the production of electricity or other power". Organizations that may acquire water licences include: water utilities, improvement districts, water districts, municipalities and B.C. Hydro. All other organizations or individuals may only acquire and hold licences if they have a real property interest in land or a mine.

Rights acquired under a licence entitle its holder to the following:

(a) divert and use beneficially the quantity of water specified in the licence;

(b) store water;

(c) construct, maintain and operate works authorized under the licence(s) for diversion, storage, distribution and use of the water or the power produced from it (s.4).

Two basic conditions must be met before the Crown will grant a licence: unallocated water must be available at your proposed point of diversion, and the water must be put to "beneficial use" (s. 4).

Failure to make beneficial use of the allocated water for three years, failure to comply with a term or condition of the licence, or failure to pay rental fees due to the Crown for three or more years, renders the licence subject to suspension or cancellation by the Comptroller (s. 2(a-f)).

It is important to note that the water licence does not guarantee that water will always be available. If there is a low water year, a priority system goes into effect, based on the principle of "first come, first served". If your neighbor secured water rights ahead of you, then he has priority in getting out of the stream you both share, the amount specified in his licence (s. 12).

If you both applied for a licence on the same day, the priority is determined by the ranking of the uses you are each making of the water, as specified in your applications. The branch has developed the following ranking system for making this assessment. From highest to lowest priority, it runs:

domestic
waterworks
mineral trading
irrigation
mining
industrial
power
hydraulicking
storage
conservation
fluming
conveying
land improvements

An additional priority exists under the British Columbia Hydro and Power Authority Act, RSBC, 1979, c. 188, and implies that a municipal small hydro plant may not be expropriated by B.C. Hydro, but an individually owned facility can be expropriated (s. 19). Also, in the case of small hydropower licences there is often a clause inserted which indicates that domestic or irrigation use has priority over power use, regardless of the date of application.

In most instances a water right under a water licence belongs, or is appurtenant to, the land on which the water is to be used, and ownership of the licence changes with that of the land (s. 13). As long as the water is used beneficially (s. 20), according to the terms of the licence and subject to the provisions of the Act, the licence stays in force, regardless of who owns the land (s. 13).

Offences

Under the Water Act, it is an offence to contravene any order of the Water Comptroller or Regional Water Managers (s. 37). The maximum penalty is a $2,000 fine or six months imprisonment or both, and if the offence continues, a fine of $500 per day will be levied. Offences are defined as placing, maintaining or making use of any obstruction in a stream without an approval or permit, and constructing any work for water diversion or use without a permit (s. 41).

The Act allows any licensee, or person having a property right in the stream bed or fishery to file an objection to any proposed application (s. 9). One provision of the Act, in particular, is important to you, and may concern your neighbors: holders of a licence for power purposes may fell and remove any tree and remove any rock or other thing that endangers his work (s. 18(2)). This means that you can remove such obstructions even if they are not on your own property. However, you may have to compensate the owner, if the Comptroller so decides.

Rentals and Fees

The Water Act provides for the Crown to establish tariffs, fees and rental charges payable in respect of applications, licences and permits, and for water diverted or used from a stream (s. 45), (Figure 2). The application fee for a power licence that includes the industrial, commercial, residential categories, is based on either of the following criteria:

(a) the intended plant installation, that is, kilowatts produced or,

(b) the anticipated additional output produced in a single normal year at all sites where the water is to be used.

As you can see, the annual rental for a licence for a power development is determined by category, according to the power rates set out in the schedule. Residential category licences pay a fixed amount, but the commercial and general categories are charged according to the applicability of the following:

(a) construction capacity;

(b) the remainder of the authorized capacity;

(c) the total energy generated during the preceeding calender year.

Where any water is diverted, stored or used for power purposes without or in excess of the quantity allowed under any licence, an annual rental shall be payable to the Crown. Review Appendix A for further detail on rental charges.

Expropriation

Once you have a water licence, you may expropriate land reasonably required for the construction, maintenance or operation of works authorized under that licence. A water licence that authorizes the construction of a dam may expropriate land that would be flooded if the dam were constructed and used to its maximum authorized height. The owner of the land is entitled compensation (s. 24).

EXTRACT FROM SCHEDULE A

POWER PURPOSE

Application Fees - All Categories

(a) When based on capacity:	
For each kilowatt	$ 1.00 (I)
(b) When based on output:	
For each megawatt-hour	$ 0.20 (I)
Minimum charge	$ 25.00

Annual Rentals - Residential Category

For each licence issued for a power development	$ 25.00

Annual Rentals - Commercial Category

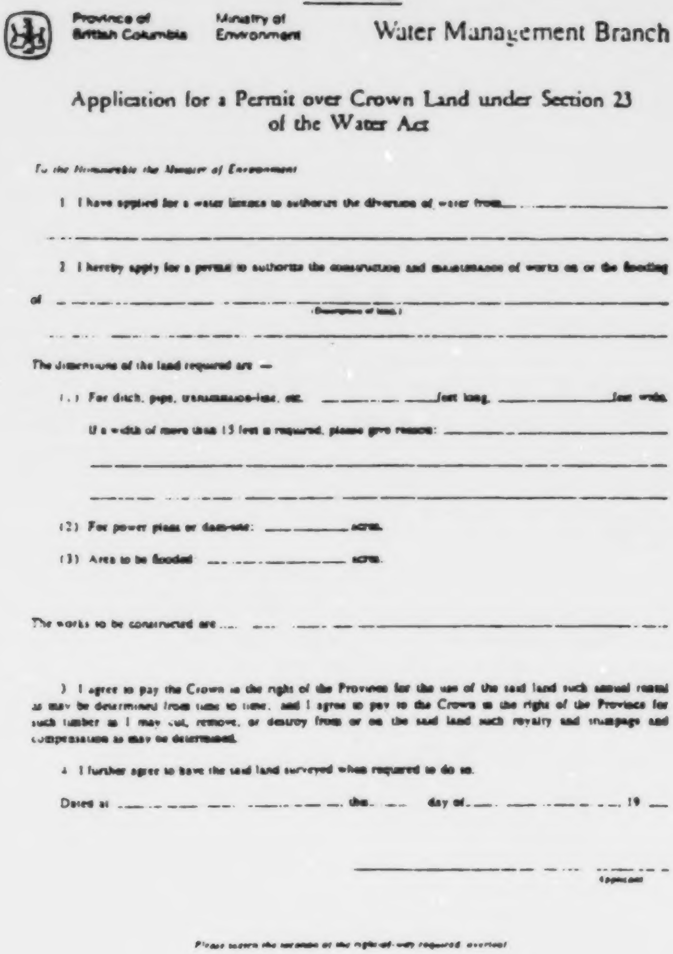
(a) Construction capacity:	
For each kilowatt	$ 0.20 (I)
(b) Authorized capacity other than construction capacity:	
For each kilowatt	$ 1.25 (I)
(c) Output:	
For each megawatt-hour	$ 0.75 (I)
Minimum charge:	
For each licence	$ 50.00

Annual Rentals - General Category

(a) Construction capacity:	
For each kilowatt	$ 0.25 (I)
(b) Authorized capacity other than construction capacity:	
For each kilowatt	$ 2.50 (I)
(c) Output:	
For each megawatt-hour up to a total of 250 000 MWh from all power developments owned by the same licensee	$ 1.75 (I)
For each additional megawatt-hour	$ 3.50 (I)
Minimum charge:	
For each licence	$100.00

(I) = Indexed

FIGURE 2



Province of British Columbia Ministry of Environment Water Management Branch

Application for a Permit over Crown Land under Section 23 of the Water Act

To the Honourable the Minister of Environment

1 I have applied for a water licence to authorize the diversion of water from ______________________________

2 I hereby apply for a permit to authorize the construction and maintenance of works on or the flooding of ______________________________
(Description of land.)

The dimensions of the land required are —

(1) For ditch, pipe, transmission-line, etc. __________ feet long, __________ feet wide.

If a width of more than 15 feet is required, please give reason: ______________________________

(2) For power plant or dam-site: __________ acres.

(3) Area to be flooded __________ acres.

The works to be constructed are ______________________________

3 I agree to pay the Crown in the right of the Province for the use of the said land such annual rental as may be determined from time to time, and I agree to pay to the Crown in the right of the Province for such timber as I may cut, remove, or destroy from or on the said land such royalty and stumpage and compensation as may be determined.

4 I further agree to have the said land surveyed when required to do so.

Dated at ______________, this ______ day of ______________, 19 ____

____
(Applicant)

Please sketch the location of the right-of-way required overleaf

FIGURE 3

CONDITIONS RELATIVE TO THE RIGHTS GRANTED UNDER THIS PERMIT

1. This permit is issued under the ***Water Act***, and the rights hereby granted are subject at all times to the provisions of that Act and all Acts passed in amendment or substitution thereof and to all regulations from time to time made under any such Act.

2. There is reserved to the Crown the right to grant to other persons permits to occupy the land affected by this permit without compensation to the permittee or his successors in title.

3. In the event of any dispute arising at any time between the permittee and any owner of land adjacent to the land affected by this permit with respect to the area or boundaries of the land so affected, the licensee shall at his own expense, when so directed by the Deputy Minister of the Environment, have the said land surveyed by a duly qualified surveyor, and shall likewise file with the Ministry of the Environment at Victoria, British Columbia, a plan showing the result of the survey.

4. This permit and the rights granted hereunder are subject always to compliance by the permittee with the terms of his water licence, and if the rights granted under the said licence should at any time be suspended or terminated, the rights granted under this permit are thereupon likewise suspended or terminated.

5. The amount of stumpage, royalty, and (or) compensation payable to the Crown by the permittee in respect of trees, including merchantable or young growth, cut, removed, damaged, or destroyed by the permittee, shall be the sum or sums fixed by the Forest Service of the Province of British Columbia. Prior to the cutting, destruction, or flooding of any timber, the permittee must apply for and obtain a licence to cut timber from the District Forester.

Crown Land

An important component of the Act is that a Regional Water Manager may issue to the water licensee one or more permits authorizing the occupation of Crown Land (Figure 3). These can cover land required for dams, power plants, pipelines, transmission lines, other rights-of-way, and reservoir flooding.

Various conditions are attached to the rights granted under these crown use permits. The suspension or termination of a water licence implies cancellation of the accompanying authorization to Crown Land use.

Where the Crown Land affected is already lawfully occupied by any homesteader, preemptor, or holder of a timber licence or lease, the applicant must obtain the written consent of the occupant, and file it with the Comptroller.

5.3.2 Water Licence

Applying for a water licence is relatively simple, and an application form may be obtained from any water recorder or regional Water Management Office. The form should be filled out completely and carefully, as errors or insufficient information can cause delays in processing the application (Figure 4). The following is a list of what you should do, and what should occur; however, some sites may require further steps.

1. List the particulars as outlined on the sample application form. These include name and address; the location of the point of diversion; the quantity of water required; a complete legal description of the property on which the water is to be used; a concise, honest description of the proposed works; a detailed diagram of proposed water systems, diversion schemes, or dam locations.

2. Post signed copies of the application near the proposed point of diversion, on a tree, post or building (this is known as "posting on the ground").

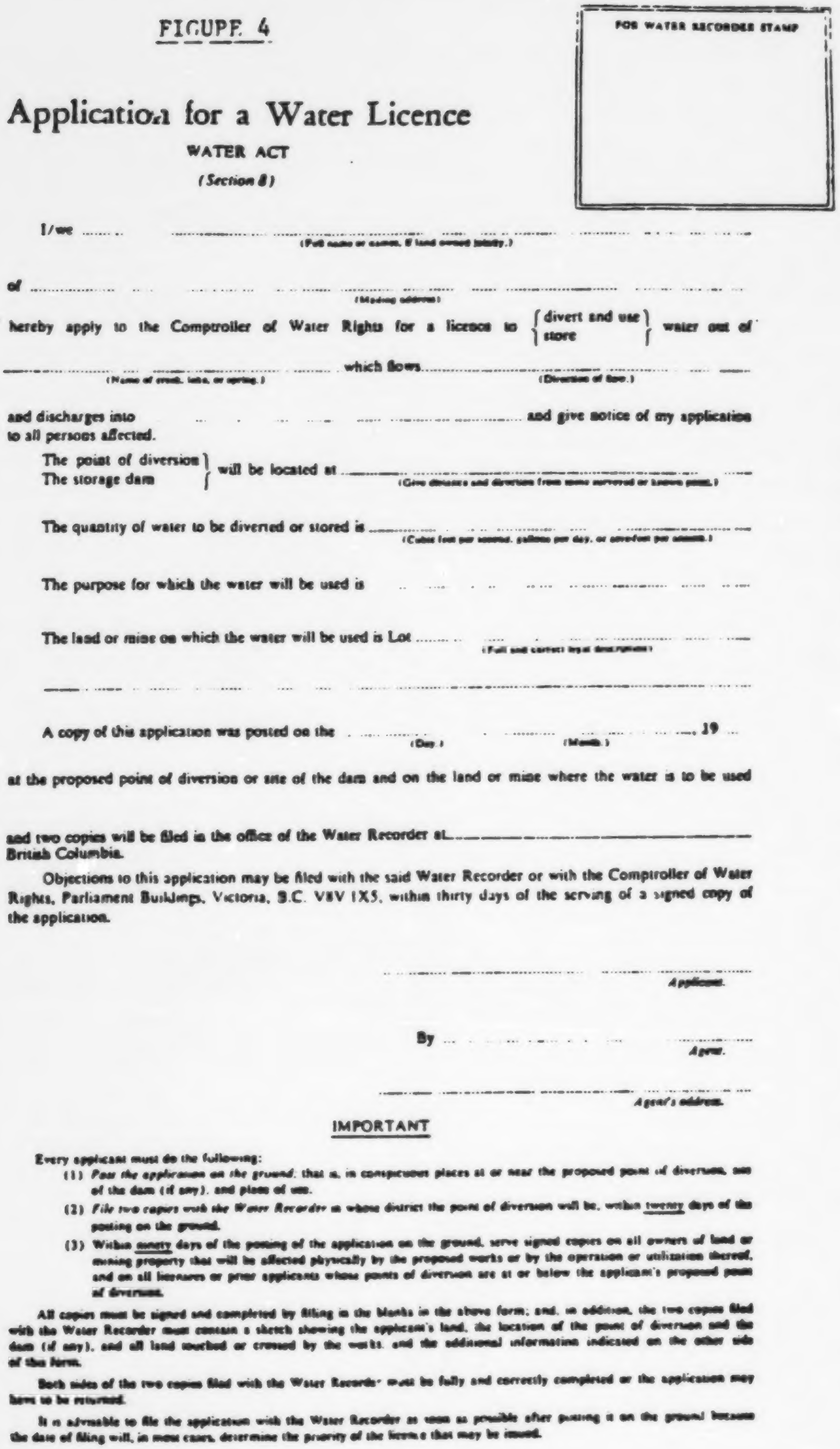
3. Within 20 days of posting, file two copies with the local Water Recorder in Victoria.

4. Within 90 days of the posting of the application on the ground, serve signed copies on all owners of land that will be affected physically by the proposed works, or are at or below the proposed point of diversion.

5. Where more than 10 persons are affected, and if so directed by the Comptroller or the Regional Water Manager, publish the application in a local newspaper in lieu of actual contact.

6. Provide the Comptroller with information concerning your title to the land, mine or premises where the water is to be used.

FIGURE 4



FOR WATER RECORDER STAMP

Application for a Water Licence

WATER ACT

(Section 8)

I/we ....
(Full name or names, if land owned jointly.)

of ....
(Mailing address)

hereby apply to the Comptroller of Water Rights for a licence to {divert and use / store} water out of

.... which flows ....
(Name of creek, lake, or spring.) (Direction of flow.)

and discharges into .... and give notice of my application to all persons affected.

The point of diversion / The storage dam } will be located at ....
(Give distance and direction from some surveyed or known point.)

The quantity of water to be diverted or stored is ....
(Cubic feet per second, gallons per day, or acre-feet per annum.)

The purpose for which the water will be used is ....

The land or mine on which the water will be used is Lot ....
(Full and correct legal description)

....

A copy of this application was posted on the ...., 19 ...
(Day.) (Month.)

at the proposed point of diversion or site of the dam and on the land or mine where the water is to be used

and two copies will be filed in the office of the Water Recorder at ....
British Columbia.

Objections to this application may be filed with the said Water Recorder or with the Comptroller of Water Rights, Parliament Buildings, Victoria, B.C. V8V 1X5, within thirty days of the serving of a signed copy of the application.

....
Applicant.

By ....
Agent.

....
Agent's address.

IMPORTANT

Every applicant must do the following:

(1) *Post the application on the ground*: that is, in conspicuous places at or near the proposed point of diversion, site of the dam (if any), and place of use.

(2) *File two copies with the Water Recorder* in whose district the point of diversion will be, within twenty days of the posting on the ground.

(3) Within ninety days of the posting of the application on the ground, serve signed copies on all owners of land or mining property that will be affected physically by the proposed works or by the operation or utilization thereof, and on all licensees or prior applicants whose points of diversion are at or below the applicant's proposed point of diversion.

All copies must be signed and completed by filling in the blanks in the above form; and, in addition, the two copies filed with the Water Recorder must contain a sketch showing the applicant's land, the location of the point of diversion and the dam (if any), and all land touched or crossed by the works, and the additional information indicated on the other side of this form.

Both sides of the two copies filed with the Water Recorder must be fully and correctly completed or the application may have to be returned.

It is advisable to file the application with the Water Recorder as soon as possible after posting it on the ground because the date of filing will, in most cases, determine the priority of the licence that may be issued.

FIGURE 4 (continued)

NOTE.—This sheet need only be completed on the two copies of the application filed with the Water Recorder.

To the Comptroller of Water Rights:

In support of my application for a water licence I submit the following information:—

(1) My title to the place of use is ....
(Whether registered owner, agreement holder, pre-emptor, etc.)

(2) The proposed works will be ....
(Give general description—pump, pipe, ditch, etc.)

....

....

....

(3) The dam to be constructed will be a .... (Type) .... dam, and will be.......................... feet in height, and .... feet in length.

(4) The maximum area of the reservoir will be .... acres.

(5) The depth of storage at the dam, from bottom of sluice-pipe to crest of the spillway, will be .... feet.

(6) The head of water to be used will be .... feet.
(For power and hydraulic mining only.)

(7) The area of land to be irrigated will be .... acres.

(8) (*a*) The works will be entirely on my own property, or

(*b*) The works will affect physically the property of the following owners:—

Name of Owner, including the Crown	Legal Description of Land	Area Required for Works	
		Length	Breadth

Sketch, showing applicant's land and all other land touched by the works or flooded, also the location of the point of diversion and other works, including buildings to be served with water, if applicable, and the lengths of all ditches, flumes, and pipes.

N.

W.

E.

S.

....
Applicant.

....
Agent.

7. Within 120 days of posting the application on the ground, file an affidavit with the Provincial Water Rights Branch stating that you have complied with points four, five and six as listed above.

8. Within 120 days, pay the application fees, and the first year's rental charges.

9. Anyone opposed to the proposed development must file a written objection to the Comptroller within 30 days of being served a copy of the application, or within 30 days of the date of the first newspaper publication.

10. Upon successful completion of the above steps, you will usually receive first a conditional licence, and then, at a later date, a final licence (s. 14).

11. Your conditional licence will require that certain obligations (such as construction of works within a specified time, maintaining works, mitigating environmental damage, and providing fish and spawning habitat) are fulfilled.

12. Failure to complete any of the above requirements can cause the application to be cancelled. A false declaration may also result in the application or the resulting licence to be cancelled.

13. See Figure 5.

Licence Conditions

Water licences frequently include special conditions for development and use of the water, to protect the interests of the general public, community water supplies or the environment.

Licences can be cancelled if these conditions are not met. Where a storage reservoir is involved, such conditions may require that water discharges be regulated in the public interest. These conditions can include flood protection, fisheries enhancement, navigation, recreation, or aesthetics. If a significant amount of timbered or uncleared land is to be inundated. You must apply for and obtain an approval or licence to cut timber from the District Forest Manager.

Standard provisions, in all licences, include: the maximum quantity of water to be diverted, the construction of works within a specified time, maintaining works as necessary, and using only the licenced amounts of water.

5.3.3 Dams or Diversions

A major dam is designated as a water-retaining structure that is 10 metres (44 feet) or more in height, as measured between the lowest

BULLETIN 2-3-0

APPROVAL OF ELECTRICAL EQUIPMENT

Rule 2-024 calls for electrical equipment used in electrical installations to be approved.

Rule 2-100 describes the marking required to identify the equipment to ensure that it is suitable for the particular installation. Among the markings listed is "evidence of approval."

Definition of "approved" as amended requires that equipment not labelled under clause (a), be approved under clause (b).

It is emphasized that approval service under clause (b) is not intended to replace C.S.A. or C.G.A. certification, but shall apply only to special or individual items of equipment designed to meet the requirements of a specific installation.

Application for special approval of equipment may be accepted by the Chief Electrical Inspector under clause (b) and at his discretion he may require that it be submitted for examination and test under clause (a).

The approval service is available only through the Provincial Electrical Safety Branch although the electrical equipment may be installed in an area where installations are inspected by inspectors employed by a city or municipality.

Application forms for B.C. approval of equipment should be obtained from any Provincial Electrical Safety Branch office or the Vancouver Head Office, completed, and returned with the appropriate fees for processing, to the Provincial Inspector in the district where the equipment is to be installed.

The remittance accompanying the application is a minimum charge and is not refundable. Because of this, all precautions should be taken to ensure that the equipment covered by the application is acceptable and that very little or no alteration or additional work will be required.

In addition to the remittance accompanying the application, the submitter must agree to pay all costs in connection with examination, tests, and labelling of equipment, including such charges as may be assessed by the testing laboratories and fees for examination and labelling in the field as prescribed in the Regulations Governing Electrical Permits and Fees Reg. 542/75 Clause 65.

The following is a partial list of the types of equipment for which application to the Chief Inspector for approval may be considered:

(1) Custom-built items, of which only one or two units will ever be built, and which have been designed for a specific job.
(2) Prototype equipment representing a pilot production run for functional testing or experimental installation.
(3) Equipment imported as settler's effects.
(4) Special equipment of standardized design not obtainable with C.S.A. certification and having no acceptable C.S.A. certified substitute.
(5) For other types of equipment the acceptability of the application must be determined on the merit of the individual case.

Self-contained battery-powered mobile or portable equipment operated at 32 volts or less, and having no integral or built-in battery charging equipment will not be required to bear evidence of approval, but will be expected to comply with the requirements of Part I of the Code, except that equipment for use in hazardous locations must bear evidence of acceptable certification for the hazard involved or shall bear evidence of C.S.A. certification as intrinsically safe.

Fire alarm electrical equipment shall be considered to be approved if it is certified by C.S.A. or Underwriters Laboratories of Canada.

BULLETIN 10-4-0

GROUNDING OF STANDBY GENERATORS

Where standby generators are installed on systems which have ground-fault protection, the grounding of the generator shall be made in such a manner that the ground detector devices will monitor the ground-fault currents.

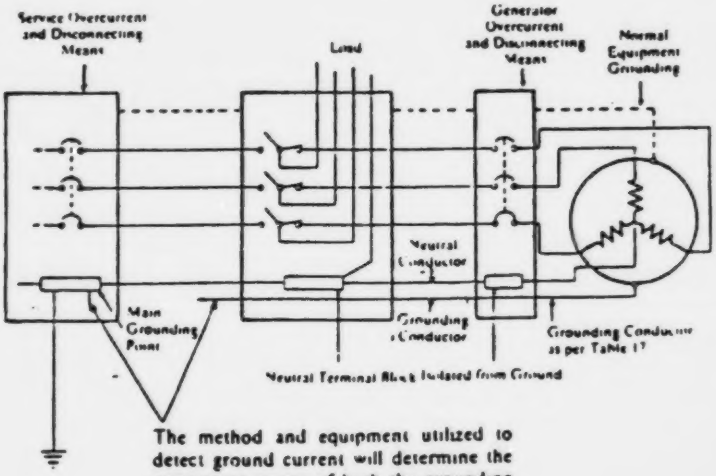
To assist in accomplishing the above and to avoid the necessity to switch the generator neutral, the following will be acceptable:

Where a generator is connected to its load through a transfer switch, the neutral may be isolated from the generator frame and connected to the main grounding point through a full capacity, insulated, neutral conductor (based on the rating of the generator over-current device) provided that:

(a) the generator is located on the same premises, and;
(b) the generator frame is connected to the main grounding point by a conductor sized in accordance with Table 17 (based on the generator full-load current rating).

It is recommended that the generator be located as close as practicable to the main service equipment to maintain the generator neutral potential at approximately the same potential as ground.

FIGURE 5


Service Overcurrent and Disconnecting Means
Load
Generator Overcurrent and Disconnecting Means
Normal Equipment Grounding
Neutral Conductor
Main Grounding Point
Grounding Conductor
Grounding Conductor as per Table 17
Neutral Terminal Block Isolated from Ground

The method and equipment utilized to detect ground current will determine the connecting points of both the grounding conductor and the bond from the neutral terminal block

NOTE This drawing illustrates one method of System Grounding interpreted

BULLETIN 14-3-0

TRANSFER SWITCHES FOR STANDBY GENERATORS

To reduce the possibility of power feedback on to Hydro lines, B.C. Hydro has introduced a procedure for examining transfer switches which are intended for connection to their system. For information regarding Hydro requirements, please contact B.C. Hydro Distribution Engineering Department, Operation and Protection Section, 1045 Howe Street, Vancouver, B.C., Telephone 663-2478.

Before an *automatic transfer* switch is accepted, the Inspector is to confirm that the switch is certified by C.S.A. as an *automatic transfer switch*. The Inspector is also to confirm the acceptance of a transfer switch by B.C. Hydro. Hydro distributes a list of switches manual and automatic which they have examined and found to be acceptable. This list will be distributed to inspectors.

Please note that automatic transfer switches are approved under C.S.A. Standard C22.2 No. 178 "Automatic Transfer Switches". Manual transfer switches are approved under C22.2 No. 4 "Enclosed Switches" point of the foundation and the dam crest, or that is classified by the Comptroller as a major dam because of one or both the following unusual circumstances:

(a) the length of the dam crest is greater than 300 metres (975 feet);

(b) the capacity of the reservoir formed by the dam is more than 616,750 cubic deca-metres (500 acre feet).

You may not begin construction on a major dam until overall plans have been approved by the Comptroller of Water Rights or, Regional Water Manager. Less stringent design standards are required for small dams, but they must perform their specified purpose without undue risk to the public. When requested by the Comptroller or in some cases the Regional Water Manager, further plans in greater detail must be submitted and approved prior to each stage of construction. Upon completion of construction, you must supply the Comptroller or Regional Water Manager with copies of the final plans of the dam and associated works.

These final plans must be certified by your construction or design engineer. Dams that are in place are inspected regularly by provincial dam inspectors. Smaller dams or diversions are inspected less regularly, depending on location and priority. Upon inspection, a certified letter detailing any maintenance requirements or upgrading is presented to the owner of the dam.

5.3.4 Electrical Safety

The Ministry of Labour is responsible for the organization and administration of the Electrical Safety Branch. The regulations followed by provincial inspectors come from the Electrical Safety Act, RSBC, 1979, c 104, as amended. These regulations ensure that certain safety standards for the generation, distribution and utilization of electrical energy are met within British Columbia.

As a small hydro power developer you will need a permit for all electrical installations, even if you are not connecting your installation to a utility grid. You can do the electrical work yourself if power is being generated for your own single family dwelling, and no other purpose. In all other circumstances, the electrical installation is to be done by an electrical contractor holding the appropriate certifications. The usual procedure is for the electrical contractor to purchase a permit, install the required electrical works, then call for a provincial inspector to inspect and approve the installation.

Inspectors are available to assist the public on matters related to electrical standards, safety, and regulation procedures. All electrical equipment sold or installed in B.C. must carry evidence of acceptable certification.

Be sure that any equipment you buy is "approved" before you buy it. Uncertified equipment can be examined under the Branch Electrical

Equipment Approval Program; and if the equipment is found acceptable, it may be identified with a B.C. Government label.

Fees are payable under the Act. Where the applicant for a permit is an electrical contractor, the fee is based upon the total cost to the owner or customer, of all labor and materials used in the electrical installation.

The registered owner of a single family dwelling, or a group of property owners, tenants or farmers are assessed fees based upon twice the value of the materials involved in the electrical installation.

If you are planning to interconnect with the provincial utility system, be sure your equipment is installed in strict accord with the utility's technical requirements. This involves installing specified protective devices, such as relays and circuit breakers to allow the small hydro plant to operate safely in parallel with the utility. Should faults or abnormal operation occur, the small hydro plant would immediately disconnect from the main system (Figure 5).

If the small hydro plant is to feed through a transfer switch, the transfer switch must be of a type acceptable to the receiving utility and approved by the Canadian Safety Association (CSA).

Early consultation with the utility will help you understand the required safety, and technical and legal requirements associated with interconnection. You should contact B.C. Hydro or the Electrical Safety Branch to help determine acceptable equipment, since both maintain considerable in-house expertise.

5.3.5 Crown Land Approvals

If you will be flooding Crown land, or building on Crown land, you must obtain Crown land approval before beginning any construction. Such approvals remain separate from those permits issued by the Ministry of Environment, and require contact with the Ministry of Lands, Parks and Housing. Crown land applications may involve further agency referrals. The referral agencies are usually Forestry, Fish and Wildlife, Parks and Highways.

The needed Crown land approvals should not take more than four or five months to get.

Legislation

The Land Act, RSBC, 1979, c. 214, as amended, is the main statute regulating the disposition of Crown lands in the province. Administered by the Ministry of Lands, Parks and Housing, the Act establishes procedures by which private individuals, corporations and associations can acquire public lands, and defines the rights that flow with the transfer.

Large areas of Crown lands are not open for disposition because they are used by the government for special purposes, such as Crown forests, parks and watershed areas.

The Ministry of Environment can also issue Crown land permits upon reviewing and accepting an application for a water licence. However these do not provide security of tenure and, except for flooding permits, should be concerted to registered easements as outlined in the Land Act.

Disposition

The Land Act provides for a number of different types of disposition of Crown lands, including the sale, lease, grant of an easement or right-of-way, or a licence of occupation (s. 8(2)). Other lesser known dispositions include: tenure for investigation of a proposed development site; and letters of consent to develop land in a specific area, for a specific tenure and purpose. All dispositions are transacted by auction, by public notice of tender, by public drawing of lots, or by application. The last method is the most common.

No Crown land may be leased for a term greater than 60 years (s. 18) except with the approval of Cabinet. No applicant can apply for a lease exceeding 520 hectares for commercial, industrial or watershed purposes (s. 20).

Any person 19 years or over, corporation or association may apply for Crown lands (s. 71). Crown grants (as opposed to other types of alienation) are now available only to Canadian citizens (s. 6). Non-Canadians whose Crown land dispositions were allowed prior to 1979 are still eligible for a Crown grant (s. 6).

The Act sketches the rough design of the system of Crown land alienation, and gives the Minister the power to set the terms and conditions of the transfer. The types of conditions attached to Crown land disposition vary depending on the intended use and type of disposition.

Crown Land Lease or Licence of Occupation

Crown land can be disposed on a lease development purchase system. After a lease is issued the lessee develops the land in accordance with the purposes for which the lease was issued. When the land has been developed, the lessee may apply for and purchase a Crown grant. A Crown grant is a document in writing conveying Crown land in fee simple (s. 1).

Land which has been leased usually involves a long term tenure of 20 years or more, and involves land area on which substantial developments are to take place. A licence of occupation is more consistent with the requirements of a small hydro developer, and involves a shorter term, minimum developments, and boundaries which are determined by "meets and bounds" criteria.

Crown Land Sale

The Minister may dispose of Crown lands by sale. To apply to purchase Crown land, you must submit the required forms (B.C. Regs. 511/79), and an application form, to the Commissioner of the land recording district where the land is located (s. 28).

Most Crown grants do not pass title to the bed or shore of a body of water, even if the body of water is included within the lands that are the subject of the grant. The exceptions are situations where there is express provision in the grant to the contrary, or the Minister otherwise directs by issuing special certificates (s. 55).

Easements or Rights-of-Way

Easement or right-of-way approvals are required if roadways, pipelines or transmission wires are required to cross Crown land. They would you to maintain operation and maintenance standards on machinery and equipment located at the hydro plant site. Statutory rights-of-way are usually granted for durations of 60 years or more, whereas easements are for shorter terms. A licence of occupation can be approved for even less time.

Unauthorized Crown Land Use

An unauthorized person may not take possession, occupy, make use of Crown land, or be the holder of a lease, easement or licence using the land for purposes not provided for in the disposition.

The agency may cease the unauthorized use and occupation of the land, through notification by mail or by posting (ss. 57, 58), and may require the payment of rent for the period the land was occupied (s. 9), and of costs of any survey carried out by the government (s. 25). Deferred payments are subject to an interest charge (s. 22).

A person lawfully entitled to occupy Crown land by virtue of a Crown disposition may take action against any person for recovery of possession, or for trespass on the land.

Tariffs and Rentals

The Ministry is also authorized to require the deposit of a bond as security for the due performance and completion of any obligations and requirements prescribed in the lease or licence (s. 32).

There is a set fee schedule for the purchase, lease, or licence of Crown land (s. 21) (Figure 6). The schedule includes time periods for payments. Deferred payments are subject to an interest charge (s. 22).

If you default on these payments, or if you fail to perform any condition set out in the disposition, your disposition may be cancelled (s. 40).

A set of fees has been established for processing applications for Crown land under the Land Act. These fees came into effect on April 1, 1981.

The charges have been designed to recover the cost of administration.

The guiding principle in establishing the fees has been a "fee for service" or "user pays" approach, and wil provide a more cost effective Crown land administration service.

SERVICE	CHARGE
For an application for a Crown grant, lease, licence of occupation, letter of consent, easement or right-of-way	$ 25.00
For an application for the establishment of a public road allowance under Section 75 of the Land Act	$100.00
For an application for a declaration of intention under Section 55 of the Land Act	$200.00
For issuing a lease or licence of occupation	$100.00
For issuing a Crown grant	$100.00
For issuing an easement or statutory right-of-way which is shorter than 25 kilometres	$100.00
For issuing an easement or statutory right-of-way 25 kilometres or longer	$200.00
For issuing a Certificate of Purchase for Crown Land	$ 50.00
For processing and approving any document evidencing the assignment of an interest passing under a disposition	$100.00
For processing an amendment to a disposition at the request of the holder of the disposition	$ 25.00
For preparing a copy of any document issued pursuant to a disposition	$ 10.00
For extracting information from ministry records	$ 25.00 per hour
For issuing survey instructions and checking survey plans for either a lease, licence of occupation, or an easement or statutory right-of-way shorter than 25 kilometres	$100.00
For issuing survey instructions and checking survey plans for an easement or statutory right-of-way 25 kilometres or longer	$ 25.00 per hour

FIGURE 6

When you have been issued a certificate of purchase and have met all the terms and conditions therein, you are entitled to a Crown grant, which transfers the fee simple interest in the property (s. 45).

Obtaining a Crown Land Permit

To obtain Crown land, you must file a formal application to the Commissioner of the land recording district in which the land is situated (s. 28(1)). No rights to the land are vested by your filing of that application (s. 52(2)): a disposition of Crown land is only binding when the certificate of disposition is released by the Crown (s.5(3)).

Before you submit the application, you must fix a post in the ground at one corner of the plot applied for, and on that post you must attach a prescribed notice (s. 28(3)). This does not apply if the application is only for a licence of occupation for a year or less, or for a grant of right-of-way or easement (s. 28(4)).

The Minister requires you to survey the land at your own expense (s. 71). The survey must be performed in accordance with the regulations of the Surveyor-General (s. 72).

The Minister may require you to publish in the British Columbia Gazette and/or you local newspaper a notice of your intention to apply for a Crown land disposition (s.29). Any person may file an objection to an application for Crown land and if an objection is received,

> "the Minister may require an applicant to obtain and file with the Minister, at his own expense, feasibility studies, environmental assessments, timber cruises, land valuation appraisals or other information required by the Minister" (s. 59).

The Minister will refer the Crown land application to those other agencies with controlling jurisdiction for areas considered to be affected by the development. For example, the Minister of Forests would be contacted if timber cutting is required within the application; or the Ministry of Environment, (Water Management Branch) if pipelines, diversions or drainage ditches are proposed.

5.3.6 Additional Referrals

When you file the mandatory water licence application and, if relevant, the Crown land approval forms, you will probably be told of any referral agency involvement. In some cases, you may have to contact those agencies to obtain permit or licence application forms, or to discuss obligations or clauses to be included with the issued water licence. You would be wise to ask which referral agencies are likely to be involved, and then contact each one as quickly as possible, describing your project and offering any information they may need.

Further agency involvement will depend on the design complexity, and the potential for environmental impact as a direct result of operating the small power plant (Figure 7). Certain agencies can impose stringent design, operation and environmental standards. Many require approvals or permits to operate within specific jurisdictions such as a provincial park, forest or ecological reserve.

Forest Lands

The Ministry of Forests manages the provincial forestry resources. The Forest Act, RSBC, 1979, c. 140, as amended, constitutes and defines the duties of the Ministry.

If your small hydro development is located in forest lands administered by either the Crown, a company or a private person, you cannot cut, damage or destroy timber, unless you have an agreement under the Forest Act (s. 138), or with the land owner.

Someone who owns forest land has far greater rights to use and develop the property than a holder of a Crown forest tenure.

You should not cut, nor remove timber to construct a road, building or transmission lines on Crown land in a provincial forest, or on land held by tree farm licence holders, without the prior written consent of the District Manager, or the managing forest company.

If you have to cut, damage, or flood any Crown timber you have two basic options. If the timber is not already committed through a tree farm licence (TFL) or timber supply licence (TSL), you can apply to the District Manager, for a licence to cut timber.

Alternatively, Ministry of Forests personnel will remove the affected timber under the small Business Enterprise Program (BEP). This means you won't have to cut, haul and yard the timber. You are responsible for contacting the District Manager should any cutting occur on lands that are not privately owned.

The Crown expects stumpage, royalty, and/or compensation for trees cut, removed, damaged or destroyed (including merchantable or young growth). This will take the form of a sum fixed by the Provincial Forest Service.

If the small hydro power project involves substantial Crown forest lands within a TFL, the Provincial Forest regulations (B.C. Reg., 562/78) may require that you obtain a special use permit (SUP) issued by the regional or district Manager (s. 2). The permit is granted only if the Manager is of the opinion that the development would be of the highest economic land use (s. 3).

If the lands are located outside a TFL, then any land use is administered through the Ministry of Lands, Parks and Housing and early agency contact should be established with the regional offices.

PROVINCIAL PERMIT AND COMPLIANCE REQUIREMENTS FOR SMALL HYDROPOWER DEVELOPMENT IN BRITISH COLUMBIA

REQUIRED ACTION	ACT	AGENCY	COMMENTS	PROCESS TIME
Water Rights	Water Act	Ministry of Environment	Water licence application must be filed; application advertised; fees required; referrals	6-12 mths
Dam Safety	Water Act	Ministry of Environment	Inspection procedures; public safety standards; referrals	Ongoing
Crown Land Access	Water Act	Ministry of Environment	Crown land use permit application must be filed; fees required	4-6 mths
Forming Utility	Utility Act	Utility Commission	Utilities regulation over 20 MW.	1-2 mths
Crown Land Lease	Land Act	Ministry of Lands, Parks and Housing	Crown land licence or lease; fees required; referrals	4-6 mths
Park Land Use	Park Act	Ministry of Lands, Parks and Housing	Park use permits; strict environmental compliance; fees	1-2 mths
Forest Land Use	Forest Act	Ministry of Forests	Cutting licence, lease, approvals; referrals; fees required	1-2 mths
Fish and Wildlife	Wildlife Act	Ministry of Environment	Environmental compliance; design standards; inspections	1-2 mths
Electrical Safety	Electrical Act	Ministry of Labour	Electrical safety, installation and regulations; fees required	1 mth
Highways	Highway Act	Ministry of Highways	Approvals to connect to highway; equipment transporation compliances	1 mth
Ecological Reserve; Heritage Site; ALR	Various Acts	Various agencies	Specific environmental compliance; set conditions for operation; referrals; on-site inspections	Ongoing

FIGURE 7

The Act also provides for a number of minor tenures issued for specific purposes. A regional manager may issue a free use permit to designated persons allowing for the harvest of Crown timber for specified purposes. The permits are issued free and have a minimum one-year term (s. 46). The regional manager can issue a licence to cut timber for people who purchase or occupy Crown land (s. 47).

The conditions concerning the disposition of Crown lands include:

1. If land is within a tree farm licence, the Ministry of Forests issues a special use permit for any land use.

2. If land is outside a tree farm licence and inside or outside a Provincial Forest, the Ministry of Lands, Parks and Housing issues tenure for land disposition.

3. All cutting of timber of Crown lands is authorized by the Ministry of Forests by the following tenures:

   (a) private land - timber removed by issuance of a timber mark;
   (b) Crown land (vacant) - timber removed by issuance of timber sale licences;
   (c) Crown land (occupied) - timber removed by issuance of licence to cut.

Provincial Parks

Land use and development is severely restricted within lands designated as Provincial Parks. The Park Act, RSBC, 1979, c. 309, as amended, defines the duties of the administering agency, the Ministry of Lands, Parks and Housing. There is currently one hydro power plant located within Strathcona Park and another plant proposed for location within the Cathedral Park boundaries.

Each provincial park is designated as Class A, B or C, and the legal position of the park depends on the designation. Permits are usually issued for Class B parks if the activity is not detremental to the recreational values of the park concerned. Class A or C designations imply that no permits may be issued unless the activity is necessary for the maintenance of the recreational values of the park (s. 8(a)(a)).

Permits are required to construct any building works; to divert or use water; or to carry on any commercial or industrial activity within a park (s. 18).

You must write to the Park Operation and Recreation Division offices supplying complete development plans, technical specifications, and any other information considered necessary by the regional district offices.

Permits are usually issued for an interim period of one year during the construction phase, with any further permits issued for a 10 year term, if all interim permit conditions have been strictly met. In the past, annual fees have been nominal, but these may be increased in the near future. The amount of fees payable depends on the complexity of the individual development, and the nature of the use for which the permit is issued.

The Division offices issue the required permits, impose conditions to mitigate any environmental degradation; and may require you to deposit a performance bond during construction, or to defray costs of restoration necessitated by your activities (s. 26).

Fish and Wildlife

The Provincial fish and wildlife resources are managed through the Ministry of Environment, Fish and Wildlife Branch. The Fisheries Act, RSBC, 1979, c. 137, as amended, provides for the management and regulation of fresh water and steelhead fish species.

The regional Fish and Wildlife branch is consulted on water licence applications if the proposed use is likely to affect fish and wildlife habitat. The agency would require evidence from you of acceptable mitigation for any construction or operational impacts on local fish and wildlife.

The Act requires that persons constructing any dam or other project that will use, divert or change the flow of any stream or river, to submit plans to the Regional District offices of that area to be affected by development (s. 28(3)). Pre-development agency contact can assist you to understand what wildlife habitat concerns and impacts to be aware of, and how to mitigate extensive damage.

No one may begin construction of any hydro project until headquarters or Regional District officers have approved the plans (s. 28(4)). You may be required to provide fish protection equipment to ensure the safe passage of fish over, around, or through the project (s. 28(1)).

Run-of-the-river developments may not appear to require such steps, but early contact with a regional Fish and Wildlife office should be made to clarify what is necessary to meet site-specific concerns.

Failure to establish protection equipment, or failure to meet conditions set out by the Fish and Wildlife Branch is an offence and liable to a fine of $100 to $1,000.

In addition, the Fish and Wildlife Branch administers and regulates provincial wildlife through the Wildlife Act, RSBC, 1982, c. 57. Regulations allow for the designation of land as a wildlife management area. The Crown has the right to take action against a person who without authority, destroys or damages riparian wildlife habitat.

5.3.7 Site Specific Referrals

Further agency involvement with a proposed small hydro plant will depend on the specific site location of the development, unusual design conditions, or specific environmental impacts.

Through various Acts, the government has acquired and set aside protected areas of natural habitat for endangered and threatened species, productive farmlands and cultural resources. The involved agencies have listings and locations of the protected habitat and significant site locations. Sensitive areas will normally be identified through the Crown land and water licence referral process. You may then be required to contact the agency responsible for such land areas. Local inquiry will quickly indicate if such circumstances are present within the proposed development area. Some potential concerns are listed here.

Watershed Areas

The Ministry of Environment has established watershed reserves in order to exercise some control over the use of lands located above the intake of a water system. Water Districts are used for administrative purposes only, and not established pursuant to particular legislation. The Watershed Regulations, (B.C. Regs. 147/59) are generally ineffective as few local governments have established the administrative machinery to enforce them.

The establishment of watershed reserves does not affect the use of private property. No permits or licences are issued by the Water Districts, and a small power development would only be reviewed as part of a referred water licence application.

Heritage Sites

The provincial Cabinet is authorized to designate any land, including land covered by water, as being of heritage significance. The Heritage Conservation Act, RSBC, 1979, c. 165, as amended, provides for the Ministry of Provincial Secretary and Government Services to administer and manage the resource.

Heritage sites cannot be tampered with or altered, unless a permit is obtained from the Minister. The Minister may impose conditions that may limit the permit to a specific time period or location, and may require a permit holder to provide reports or plans to the Minister concerning any works or construction on the property (s. 5). The permit may be cancelled or suspended for failure to comply with the imposed obligations. In most cases, you will not interact with, or require construction on, or near a heritage resource.

Prior approval would be required if the flooding of lands for reservoirs or water storage had any impact on adjacent heritage structures or sites.

Agricultural Lands

The Agricultural Land Commission Act, RSBC, 1979, c. 9 is a complicated land use control statute. It establishes the Provincial Agricultural Land Commission to act as an agricultural land zoning authority. It designates agricultural land, whether public or private, as an agricultural land reserve (ALR), and regulates activity within the reserve.

The Act prohibits the occupation or use of land within the agricultural land reserve for any purpose other than farm use, "except as permitted by the Act, or order of the Commission".

The Regulations set out the procedure by which private individuals may carry on a non-farm use, and require that a detailed application be submitted to the Commission by the owner.

If you are proposing small hydro facilities within the ALR boundaries, you likely will not require Commission approval, unless you are flooding lands, timber and suitable agricultural soils.

Ecological Reserves

The Ecological Reserve Act, RSBC, c. 101, empowers the provincial Cabinet to reserve public lands within the province for ecological purposes. The Ministry of Environment administers and regulates the reserve lands, and has closed a number of ecological reserves to all use or entry without an authorized permit.

It is highly unlikely that your project would be in one of these areas. If it were, you would be warned early in the water licence application stage.

The issued water licence would then impose specific conditions to mitigate environmental damage to the ecological reserve area.

Highways

The Highways Act, RSBC, c. 167, sets out powers and duties of the Ministry of Highways. You construct a road into a potential hydro site, and the new road connects with an existing provincial highway, prior approval must be obtained from the regional Highway offices. Specific conditions may be attached to the approval. These can include specific road gradients, ditches and runoff drainages, and the posting of warning signs. Conveyance of water across a highway or road by pipe, penstock of flume is also subject to prior approval by the Ministry.

The Highway Industrial Act, RSBC, 1979, c. 168, defines and regulates roads used exclusively for the construction and maintenance of electrical power lines, telephone lines or pipelines. Such compliance would normally concern a plant used in connection with heavy resource extraction activities.

When a hydro development requires transporting oversize or overweight equipment over a provincial highway or road, permits must also be obtained from Provincial Motor Vehicle offices. You must comply with the requirements of all provincial Weigh Scale operators and follow prescribed procedures when transporting such equipment.

5.3.8 Approval, Permits and Licences

The following is a summary of approvals, permits and licences which you might require:

(a) Water licence and dam construction compliances;

(b) Utility regulation; exceeding 20 MW require operation and construction certificates; and if less than 20 MW and for public sale of electricity then a certificate of public convenience and necessity;

(c) Crown land permit (short term tenure, pipelines, penstocks);

(d) Electrical installation permits, and CSA equipment approvals;

(e) Crown land lease, licence or permit;

(f) Forest land cutting permits or (SUP);

(g) Park use permits;

(h) Highways permits, Motor Vehicle permits and licences;

(i) Environmental approvals and water use clauses and obligations attached to the water licence as recommended from the Ministries of Parks, Forests, Fish and Wildlife and other concerned agencies.

5.4 FEDERAL GOVERNMENT

The Federal government approvals and permitting requirements extend to power projects that involve fisheries, federal lands, navigable or international waters, or affect provincial or international commerce.

It is your responsibility to make initial contact with the necessary regulatory agency, to provide required information, and to work closely with officials as a site study progresses. All water licence applications are referred for review and comment to the Federal Fisheries Department.

Fisheries

The Fisheries Act, RSC, 1970, c. F-14, as amended, is the federal statute controlling waters frequented by fish, and includes most B.C. lakes, rivers, and coastal waters.

The Department of Fisheries and Oceans administers and regulates all activities within such water bodies, and reviews all referred water licence applications including those for power developments.

Any development on rivers and streams that support anadromous fish (which return from the ocean to spawn in B.C. streams) is of interest to the Department. Biological impacts can occur in two different stages of small power development: (a) during construction when there can be significant but temporary impacts; and (b) during the actual operation of the system, when there may be more permanent impacts.

During construction, concern will focus on water flow quality and siltation. Long term operational impacts may include reduction in water flow, interference with downstream gravel transport, entrainment of fish at the diversion, or attracting fish at the return flow area.

Stream side activities that encourage soil instability, erosion, habitat alterations and reduced downstream water quality resulting in decreased fish egg survival would also be of agency concern.

Mitigative items that should be kept in mind when designing, building and operating projects include:

(a) timing of construction activities to minimize impacts;

(b) providing fish passage structures and intake screenings for fish;

(c) burying pipelines and penstocks where possible;

(d) developing and maintaining a flow regime that protects fish habitat;

(e) where applicable (dams or diversions) changing the flows of rivers at gradual rates to protect fish; and

(f) post-construction monitoring.

You should establish early contact with the regional offices, to present accurate site feasibility studies. These may include consulting or engineering studies, or concise site diagrams such as those requested on water licence application forms. You can save time and effort by incorporating agency suggestions for mitigating environmental impacts. Such cooperative consultation has, in the past, helped fish spawning habitat co-exist with many small hydro power operations.

In due course, the regional office will receive the referred water licence application. It will then assess the development and, when warranted, recommend mitigative measures or obligations to be included on the water licence, or during actual plant construction.

Site inspections of the project area are undertaken with you to help address any particular concerns or questions.

Further information and study before development begins can be requested by fisheries officers if the quality of the design is poor, or if it is considered dangerous to the local environment.

Fisheries officers have the power to suspend construction or operation if any design obligations, or water licence conditions are abused or ignored.

A number of section of the Act deal specifically with obstructions in rivers or streams, and include dams, weirs and diversions. Consultation with regional offices will help you determine if sections 20, 24, 27, 31 and 33 of the Act are applicable.

National Parks

The National Parks Act, RSC, c. 189, is the federal statute controlling development of federal lands designated as National Parks within British Columbia. The regional offices of Parks Canada administer and manage the resources found within the park boundaries.

There are five National Parks in British Columbia: Pacific Rim, Yoho, Kootenay, Glacier and Mt. Revelstoke National Park. Pacific Rim National Park boundaries are not established by statute, but are designated lands within the Renfrew, Barclay and Clayoquot Land Districts on Vancouver Island's west coast.

Lands within a National Parks my be disposed of, but only in accordance with the Act and its regulations (s. 6(1)). For example, park lands may be disposed of through selling or leasing for electrical transmission lines (ss. 6, 7). Park officials exercise control to ensure that all park leases (temporary or permanent) are compatible with a park environment.

Parks Canada approval to withdraw, divert or utilize park water requires formal application by written letter and should include the following information:

(a) an introductory statement;
(b) the location of the project;
(c) a description of the proposed project, including civil and mechanical structures;
(d) average power production;
(e) a description of studies to be conducted;
(f) projected costs; and
(g) possible expected sources of funding.

Parks Canada would respond explaining the conditions under which the water permit is to be issued, and listing any rehabilitation or other specified obligations to be followed by the development. You should adhere to an orderly and scheduled operational plan, in conjunction with the interim permit conditions and obligations. The installation of equipment and construction activities would only be authorized if the continued preservation of the park lands is assured.

Park officials monitor all significant construction and operation activities, and have suspension or cancellation authority for poor construction performances, and environmental degradation.

Parks Canada is unlikely to encourage hydropower developments within National Park boundaries, unless the development is necessary for maintaining the integrity of the area as a public interest consideration.

Native Lands

Within British Columbia there are many Indian reservations and associated lands. The Indian Act, RSC, 1970 c. I-6, as amended, provides for Indian "Reserves", where native people can live with special rights. You should contact the Deparment of Indian and Northern Affairs if your potential development is on lands that border Indian reservations, or on rivers flowing onto Indian lands. Three provincial reserves receive electricity for community power needs from small hydropower plants operating on adjacent Crown land.

Development on the Indian reserves rests with Band Councils, which have power to enact by-laws regulating land use. Councils have some control over the environmental quality of their reserve land area, and indirectly on adjacent private or Crown lands.

Development of rivers or streams on the Indian reserve usually requires acquisition of a provincial water licence, yet no application fees are payable, provided the land is not leased to or occupied by any person who is not a Native Indian.

Power plants operating adjacent to native lands, must not significantly affect the quality of the human or natural environment within the reserve. Therefore, developments requiring impounded, diverted or modified water regimes flowing onto an Indian reserve, require prior approval and authorization from the Department of Indian and Northern Affairs.

Permission would be required for the use of any reserve lands for right-of-way access roads, transmission lines, canals, and penstocks. If you wish to supply Indian communities with electrical power, authority is required from the Band Council and Indian Affairs. Specific sections of the Act detail the procedures and requirements to be undertaken in such a development situation (s. 28.2).

Any provincial water licence application that could significantly affect reserve lands would be referred to Indian and Norther Affairs. The Department can further stipulate conditions or obligations you must perform to safeguard reserve lands.

5.4.1 Additional Federal Approvals

There are numerous other Federal laws and jurisdictions that may be applicable when considering developing hydropower plants within British Columbia. In most cases you will not become involved with any of them yet they are presented as potential restraints to development.

1. The Navigable Waters Protection Act, RSC, 1970, c. N-19, aims at preventing interference with navigation on rivers, that are actually capable of navigation.

2. The National Energy Board Act, RSC, 1970, C. N-6, as amended, requires that companies dealing with international power lines possess a permit, and the Board is authorized to issue licences and set terms for the export of electrical power.

3. The Dominion Water Power Act, RSC, 1970, C. W-6, deals with water power generated on Federal public lands. No licences have been issued in B.C., as power has not been generated on Federally owned lands.

4. The Canada Water Act, RSC, 1970, C. 5, authorizes the federal government, along with the province, to manage the country's water resources. There are no accompanying regulations, and it carries little legal clout.

5. The International Boundary Waters Treaty Act, RSC, 1970, C. I-20, empowers an established Commission to evaluate proposed hydropower developments to be constructed on Canadian waters flowing across the boundary into the United States.

6. The International River Improvements Act, RSC, 1970, C. I-22, regulates public and private construction activities on international rivers.

5.4.2 Federal Approvals, Permits and Licences

The following is a summary of Federal approvals, permits and licences which may be required:

(a) Federal fisheries approvals and environmental compliance;

(b) National Park use permits and approvals;

(c) Native land use approvals and permits for on-reserve construction or electrical installations;

(c) Various specific international approvals (of lesser significance) for small hydro developments.

5.5 RECOMMENDATIONS

1. Contact the Ministry of Environment, Water Rights Section to explain the proposed project, to obtain a water licence application, and to determine what (if any) additional agency permits, licences or compliances might be required;

2. Contact the referral agencies (Federal Fish, Fish and Wildlife, Forestry or Parks) early in the approval process, to incorporate suggestions or improvements into the actual design. This can save both time, effort and possible expense in the future.

3. Contact the British Columbia Utilities Commission if supplying or selling power to neighbors, communities or industries.

4. Complete all application forms in a clear and concise manner, and provide legible, accurate diagrams where applicable;

5. Ask questions if unclear on any requirements; and understand the possible referral process, and the reasons for potential approval delays.

6. Obtain a clear understanding of all possible rental and application fee charges payable in respect of a permit or licence application, and the length of time the approval remains in force.

7. Obtain copies of applicable provincial legal statutes (for example the Water Act and regulations). When operating within various legal jurisdictions, possessing the regulations can alleviate quickly any misconceptions over process or procedures. Pleading ignorance of the law does not prevail in a court of law.

8. Keep a file with the copies of all agency correspondence for handy reference, and keep a checklist of agencies to contact and approvals to be obtained or still outstanding.

9. Develop agency contact for information.

10. Contact Energy, Mines and Resource for additional information on all aspects of small hydro implementation.

APPENDIX A

General Information on Water Law in British Columbia

The Crown owns all water and permits the use of it only by licence under the *Water Act*. A WATER LICENCE is a legal document issued by the COMPTROLLER OF WATER RIGHTS, which specifies the conditions governing the right to the use of water. These conditions, or TERMS of the licence, include a statement of

(*a*) the source of water supply;
(*b*) the point of diversion from the stream;
(*c*) the priority date of the licence;
(*d*) the purpose for which the water is to be used;
(*e*) the maximum quantity of water which may be diverted;
(*f*) the period of the year during which the water may be used;
(*g*) the land to which the licence is appurtenant; and
(*h*) the works authorized to be constructed to collect and convey the water from the stream to the place of use.

Without a water licence it is illegal for any person to divert (or take) *surface* water from any stream except for fire-fighting, and, provided the water is *unrecorded*, for domestic use or for prospecting. UNRECORDED WATER is the supply available in a stream in excess of the total quantity for which licences have been issued.

Under the *Water Act* a STREAM means any natural watercourse or source of water supply, whether usually containing water or not, and includes *groundwater*, and any lake, river, spring, swamp, creek, ravine, or gulch. SURFACE WATER is water above the surface of the ground and, conversely, GROUNDWATER is water below the ground. The *Water Act* does not at present apply to groundwater. Therefore, a licence is not required for a WELL.

A water right belongs, or is APPURTENANT, to the land on which the licence authorizes the water to be used. As long as water is BENEFICIALLY USED, according to the terms of the licence and subject to the provisions of the *Water Act*, the licence stays in force, regardless of who owns the land. The person who is legally entitled to possession of the appurtenant land (usually the assessed owner) automatically becomes the licence holder or LICENSEE.

Every water licence carries a PRIORITY DATE, set by the Comptroller when he issues the licence. The priority date is usually the date when the licensee filed his application for a licence. When more than one licence has been issued on the same stream, the person holding the earliest priority licence has first call on the available supply, or FIRST RIGHT to the use of the water. The person who holds the licence with the next later priority date has second right, and so on. If a stream does not carry enough water at times to satisfy all of the licensed diversions from it, then the person holding the latest priority licence is the first who must stop using water, because his junior right licence is subject to the prior rights of the other licensees.

The rights exercisable under any two licences of *equal* priority date have precedence according to the purpose for which the water may be used, in this order: Domestic, waterworks, mineral-trading, irrigation, mining, industrial, power, hydraulicking, storage, conservation, fluming, conveying, and land improvement.

A water licence does not authorize the licensee to enter upon privately owned land. Before constructing the works authorized under his licence, the licensee should first get permission of every property owner whose land the licensed works will cross, preferably by negotiating a formal easement across each parcel of private land and having this registered in the Land Title Office. Verbal agreements are not binding and for that reason are not always satisfactory. If an agreement for entry on private land cannot be negotiated, the licensee can EXPROPRIATE an easement over any land reasonably required for the construction and maintenance of the works authorized under his licence. If the works cross Crown land, a permit to authorize this can be obtained upon application. If this Crown land is subsequently sold, the Crown grant will contain a reservation which will in effect give the licensee an easement over the land.

The foregoing is a summary of how the use of water is governed in British Columbia. If you require more specific information, or if you wish to apply for a water licence, contact your local Regional Water Manager. Offices are located in Victoria, Nelson, New Westminster, Kelowna, Kamloops, Prince George, Smithers, Williams Lake, Cranbrook, Oliver and Nanaimo.

MINISTRY OF ENVIRONMENT
WATER MANAGEMENT BRANCH
Parliament Buildings

Extracts from the Water Act Regulations

Regarding Rentals upon Power Developments

5.02 The application fee for a licence for power purposes, all categories, shall be based on

(a) the rate for capacity in Schedule A and the intended authorized capacity, where the applicant intends to install generating equipment, and

(b) the rate for output in Schedule A and the anticipated additional output produced in a single normal year at all sites where the water is to be used, where the applicant does not intend to install generating equipment

with a minimum charge, not indexed, as set out in Schedule A. (O.C. 2889/80.)

5.15 The annual rental for a licence for a power development shall be determined according to category at the rates in Schedule A and for the commercial and general categories there shall be a rental charge on

(a) construction capacity,

(b) the balance of the authorized capacity not included under construction capacity, and

(c) the total of the output from all power developments owned or operated by a single licensee during the preceding calendar year. (O.C. 2889/80.)

5.24 The Comptroller may determine the authorized capacity of a power development at the total name-plate rating of all units, including any units still to be placed in service, or at the amount of power he estimates could be developed from the total licenced flow.

5.25 The licensee of a power development shall submit records of operation and other relevant data to the Comptroller who shall use the information to determine the fees, rentals and charges on the output of that power development. (O.C. 2889/80.)

5.26 If the owner of an existing power development has applied to the Comptroller for permission to replace part or all of the development with new equipment, the Comptroller may authorize the replacement of the said equipment under such terms as he sees fit, and the rentals to be paid thereon during the period of replacement shall be at the rate specified for construction capacity. In the event that the capacity of a plant can be increased without requiring additional quantities of water, the rentals to be charged during the period of reconstruction shall be based on the former authorized capacity until such time as the new equipment is placed in operation; but if additional quantities of water are required the rentals shall be based on the higher amount of authorized capacity.

5.27 When, at a power development, construction capacity becomes operational during the course of a year, the rental rate to be charged in accordance with Schedule A shall change, with effect from the actual day upon which the capacity becomes fully operational. When any capacity is taken out of service for replacement as authorized by the Comptroller, the rental rate for construction capacity, as shown in Schedule A, shall apply with effect from the day upon which the capacity is removed from service and shall continue to apply until the said capacity, or each portion thereof, is placed in operation once more.

5.28 Where all or part of the authorized capacity at a power development is not electrical in nature, the electrical equivalents for capacity and output may be determined, for rental purposes, by assuming that one kilowatt is equal to 1.341286 horsepower.

5.29 (1) In this section "downstream owner" means owner, part owner or operator of a downstream plant outside the Province.

(2) Subject to section 5.30, where the holder of a licence for storage purposes

(a) operates the storage facilities for the purpose of enabling a downstream hydro-electric plant outside the Province to generate greater amounts of electricity than the level it could generate if the storage facilities were not so operated, and

(b) receives a benefit for doing so from a downstream owner,

then, in addition to any fees, rentals or charges payable by the licensee for storage purpose under any other section of this regulation, he shall pay the fees determined under this section.

(3) The additional fee referred to in subsection 2 shall be determined at the appropriate rate for annual rentals upon output.

(4) The rate for output shall be the higher of

(a) the rate applicable to the licensee in calculating the other annual rentals upon output payable by him under this regulation, or

(b) the rate that would apply to the downstream plant if it were in the Province.

(5) Where the licensee is also the downstream owner, the additional fee referred to in subsection (2) shall be based on the amount by which the hydroelectrical energy available at the downstream plant increases due to the operation of the upstream storage facilities.

(6) Where, in return for operating the upstream storage facilities, a licensee who is not a downstream owner receives hydro-electrical energy from a downstream owner, the additional fee referred to in subsection (2) shall be based on the amount of hydro-electrical energy so received.

(7) Where, in return for operating the upstream storage facilities, a licensee who is not a downstream owner receives benefits other than hydro-electrical energy from a downstream owner, the additional fee referred to in subsection (2) shall be the fee that the licensee would be required to pay under this section if he were a licensee described in subsection (6) and receiving 1/2 of the amount by which the hydro-electrical energy generated by the downstream plant is increased due to the operation of the upstream storage facilities.

(8) Fees determined under this section shall be payable in the calendar year following that in which the licensee incurs the fee, but for the purpose of any fee calculation under this section the rate for output shall be the rate for output for the calendar year in which the fee is payable, notwithstanding that the licensee incurred the fee during the preceding calendar year. (.O.C. 1105/84)

5.30 Section 5.29 does not apply to those portions of the downstream power benefits described in the Columbia River Treaty that were sold within the United States of America under the terms of the Sales Agreement of 1964. (O.C.2889/80)

5.31 Where a fee, rental or charge in Schedule A is indicated as being indexed, the amount due for the current calendar year shall be computed using the rate shown in Schedule A, the base rate, multiplied by an indexing factor determined in accordance with the procedures set out in Schedule C. (O.C. 2889/90)

5.32 Where a fee, rental or charge in Schedule A is indicated as being indexed and is multiplied by the indexing factor, the result shall be rounded off to the nearest tenth of a cent. (O.C. 2889/80.)

5.33 (1) Where the total amount of annual rentals for a calendar year payable by a licensee on all licences held by him exceeds $100 000, the total amount shall be paid in two installments, the first installment due by March 31 of that year and the second installment due by September 30 of that year.

(2) Where, under subsection (1), the total amount is known on January 1 of that calendar year, the two installments shall be equal in amount, but where the total amount is not known on that date, the first installment shall be based on 1/2 of the amount of water diverted or power produced during the latest year for which information on water diverted or power produced is known, and the second installment shall constitute the balance of the rental due.

(3) Where an installment is not paid by the due date in accordance with this section, percentage additions of 1.5% shall be added on the following day and on the first day of each succeeding calendar month until the total amount due, including the percentage additions, are paid. (O.C. 1105/84)

5.34 The various categories of power developments are

(a) "residential", being a power development not exceeding 25 kW of capacity and supplying one household only,

(b) "commercial", being a power development not defined in paragraph (a) and not exceeding 499 kW of capacity, the energy from which may be sold to the immediate family members, employees or tenants of the licensee, and less than 5% of the total generation is sold to other persons,

(c) "general", being a power development not defined in paragraph (a) or (b). (O.C. 2889/80)

5.35 Notwithstanding any other provision of the regulation, section 5.07 and 5.15 shall not operate to require a licensee to pay annual rental in respect of hydro-electrical capacity, energy or both that the licensee is obliged at law to deliver free of charge to an owner or operator of a downstream hydro-electrical plant outside the Province as compensation for losses of hydro-electrical capacity, energy or both at that plant suffered as a result of

(a) the licensee's operation of the upstream storage or power facilities that are the subject of his licence, or

(b) filling the licensee's reservoir for the first time. (O.C. 1105/84).

SCHEDULE C

Indexing Factor for Indexed Fees and Rentals under "POWER PURPOSE" in Schedule A

1. Calculation of the indexing factor, with respect to fees and rentals under the heading "POWER PURPOSE" in Schedule A, to be used with base rates indicated as being indexed shall be in accordance with the following steps and in this section "initial year" means "the year ending March 31, 1982":

   (a) refer to the latest annual report of the British Columbia Hydro and Power Authority published before January 1 or the year for which the fee, rental or charge is to be determined;

   (b) obtain from the annual report the figures set out in the Table of Financial Statistics for Sources of Revenue, Electric

      (i) for the year prior to the most recent year, and
      (ii) for the initial year;

   (c) obtain from the annual report the figures set out in the Table of Operating Statistics, Electric for Total Electricity Sold (kWh in millions)

      (i) for the year prior to the most recent year, and
      (ii) for the initial year;

   (d) divide the figure obtained in paragraph (b) (i) by the figure obtained in paragraph (c) (i) and express the result in dollars per megawatt-hour;

   (e) divide the figure obtained in paragraph (b) (ii) by the figure obtained in paragraph (c) (ii) and express the result in dollars per megawatt-hour;

   (f) divide the figure determined in paragraph (d) by the figure determined in paragraph (e) and the result is the indexing factor.

[O.C. 2653/81, O.C.1809/83, O.C.2284/84]

6.0 ECONOMICS AND FINANCING

6.1 INTRODUCTION

The economics of a small hydro development are crucial in determining overall project feasibility. In some ways, the technical feasibility of a project is more readily established than the financial viability. To say that a project is feasible because a turbine can be installed in a river to generate electricity, begs the question of whether it would make any sense to do so. The economic analysis is designed to answer this question and the financing plan is necessary to establish whether, or how, it can be done.

The principal objectives of the economic analysis can be described as follows:

(a) ensure most efficient use of resources;

(b) compare development options in terms of scale and risk;

(c) compare hydro with other power options; and

(d) decide whether to implement a project.

The methodology of the economic analysis explicitly addresses efficient use of resources. It is designed to summarize the economic impacts of project development such that the results are readily interpreted to rank project alternatives and to determine whether a particular project represents a good investment.

The financial analysis and the development of the financing plan provide a means for achieving additional objectives:

(a) maximization of investor wealth;

(b) determination of revenues and funding requirements;

(c) identification of funding sources; and

(d) means for explicitly addressing risk elements.

The economic and financial considerations necessary for determining project feasibility cannot be viewed as isolated elements or a distinct step in the process. Rather the analyst needs to be constantly mindful of the impacts that a whole range of preliminary decisions arising from the engineering analysis will have on project economics. Depending upon the complexity of the project, it may be necessary to conduct economic assessments at various stages of the project. As more information becomes available from the technical and hydrologic investigations, the quality of the economic analysis will obviously improve and become more detailed. Still, it would not be appropriate to leave all considerations of economics until after all of the engineering is in hand, since the economic assessments should be used as screening and ranking tools to yield a process of elimination as project alternatives are considered.

The economics of the project will be significantly influenced by the technical design, hydrology and power, and capacity decisions. However these decisions cannot be made independently from economic considerations. Thus an iterative or staged recognition of economic influences must be built into the feasibility assessment process.

Whether the economic assessment is at a conceptual stage or a detailed final feasibility stage, you will need to collect several items of data before starting. The basic data requirements are as follows:

(a) energy and generation capacity estimates for each alternative;

(b) capital and operating cost estimates for each alternative;

(c) user demand patterns and growth projections; and

(d) interest rates and projected future changes in rates.

If the economic analysis is to be conducted at the conceptual or pre-feasibility stage, the detail will obviously be limited. However, significant time and cost can be wasted if the economics are not examined even at this stage.

6.2 VALUATION OF ENERGY

No one is interested in developing a stream or river to produce electricity per se. The demand for electricity is derived from users of the power and the value of the power depends on the use that will be made of it and the alternative means of obtaining it. Electricity is desired for what it can do, not for what it is.

Thus, a critical question early in the economic analysis becomes: "What is a hydro development worth?"

For the purposes of the economic analysis, the value of small hydro is the stream of future benefits it can provide, or the stream of costs which can be avoided. These avoided costs are primarily associated with the alternatives to the small hydro project.

In most instances, the relevant alternatives will be diesel generation or connection to the provincial hydroelectric grid. In many cases, diesel electricity may already be available. Thus, the economic analysis becomes a comparison of the capital and operating costs of the small hydro development against those associated with diesel generation.

The cost comparison between hydro and diesel will differ in some respects, depending on whether diesel electricity is already being supplied. If so, the comparison will focus on the costs of hydro with the costs of continuing the diesel operation. If diesels are not already being used, then the installation costs for these must be included in the analysis as well.

The comparison between hydro and diesel will also be influenced by whether the firm hydro power (minimum amount available) will be sufficient to supply the peak electrical load expected. Under these circumstances, a small diesel might be required for emergency back-up power but only minimal operating costs would be expected. However, where the hydro alternative will not satisfy peak loads, then more extensive diesel generating capabilities will be required and the operating costs for the diesels could be a major factor in the analysis.

6.3 ALTERNATIVE ENERGY COSTS

For any power generation alternative, the relevant costs to be identified and quantified will be capital costs and operating and maintenance costs. Thus, you decide to generate electricity with diesel, there will be a capital cost associated with the purchase of the diesel engine and generator set, fuel tanks, electrical switch gear and wiring, etc., as well as transmission line from the generator to the end-use point. The primary operating cost will be the diesel fuel for the engine while maintenance costs will include lubricants, inspections, engine tuning and adjusting, spare parts and so on.

Diesel generation is typically characterized by relatively low capital costs but high operating costs. As a result the initial cash outlay for obtaining electricity from diesel generators is not as large as many other alternatives, but the cash drain associated with fuel purchases continues for the life of the operation.

The other aspect of evaluating energy costs depends on the amount of energy beneficially used. Diesel generating systems are relatively flexible since the supply will, within certain bounds, react to the demand. The engine will not speed along producing 200 kW when only 100 kW are required. This is not necessarily the case with hydro generation. The energy available from hydro, or from grid connection, is independent of the level of demand at any particular point in time.

For example, a transmission line from the grid might cost $100,000 to install and the financing costs for this line might be $10,000 per year. If you require 10,000 kWh's of energy, then obviously the financing portion of the costs will be $1.00 per kWh. However, if another user can take 100,000 kWh, then these costs fall to only 10¢ per kWh.

For the initial examination of the economics of alternative sources of electrical energy, levelized unit costs should be calculated. A levelized unit cost combines capital and operating costs associated with the source and implicitly recognizes the length of time the facility will provide economic returns.

Example: Levelized Unit Costs

The following discussion illustrates the calculation of levelized unit costs for diesel generated electricity.

Assume a farm requires a 100 kW diesel generator. The manufacturer's price for a suitable unit is $28,000. In-shop testing, delivery, construction of a concrete pad and building enclosure, connecting lines to farm buildings, spare parts and filters, fuel storage tank and fuel pump, and field start-up are estimated to add another $25,000. The resulting total capital cost is $53,000 for this example.

(Note: 1985 Prices for diesel generator sets in the less than 1000 kW capacity range run about $200 per kW capacity for the larger machines (500 kW to 1000 kW) to about $280 per kW for smaller units (50 kW). Units of 250 kW capacity cost about $215 per kW. These rule of thumb prices are FOB Vancouver.)

Installed prices will be very site specific. Typically, installed prices will range between 1.5 times and 2.5 times the purchase price of the diesel generator set depending on remoteness, access, storage requirements, operating conditions and other circumstances.

Assume also that the demand analysis reveals that the expected peak demand is 88 kW and the average annual energy required will be 310,000 kWh (i.e., average load of about 36 kW). Fuel consumption will represent the largest cost associated with generating this electricity. Small diesels are capable of fuel conversion ratios ranging between about 2.2 kWh and 3.1 kWh per litre of diesel fuel, depending on the intrinsic efficiency of the engine and the load pattern. For this example, a conversion efficiency of 2.8 kWh/litre is assumed and the cost of diesel fuel is assumed at $0.40 per litre.

Other operating and maintenance costs will include routine inspections, oil and fuel filter cost, oil changes, engine tuning, and so on. For small installations, these items can amount to about 10 percent of capital costs, or in this case, $5,300 per year.

A final cost category which cannot be overlooked in the evaluation of diesel energy is the cost of overhaul. The cost to be included here depends on the planning horizon of the analyst.

Generally, in situations where small hydro is under consideration, the planning horizon must be relatively long, since it will rarely make sense to incur the capital costs associated with hydro if the expectation is abandonment be abandoned in only a few years. Although the actual lifespans of some hydro developments may exceed 50 years, 20 years is commonly used as a basis for evaluation. Diesel engines to not have such lengthy lifespans, however. A continuously operating diesel might run as long as 10 years if properly maintained. At that point, however, it must either be replaced or completely overhauled. The overhaul option is generally

TABLE 6-1

ASSUMPTIONS FOR CALCULATING DIESEL GENERATION COSTS

Capital Cost	$53,000
Annual Energy	310,000 kWh
Fuel Cost	$0.40/litre
Operating & Maintenance Costs	$5,300/yr.
Project Life	20 yrs.
Generator Conversion Efficency	2.8 kWh/litre
Overhaul Cost (after 10 yrs.)	$25,000
Real Interest Rate	10% per annum

the lowest cost alternative and would be expected to amount to about $25,000 for the unit being considered in this example. Thus, if the planning horizon is 20 years, provision must be made for a $25,000 overhaul after 10 years.

The final item of information necessary to calculate unit costs for this diesel example is interest rates. For economic analysis, it is simpler to use "real" interest rates. The rates quoted by the bank are "nominal" rates which include two components: expected rate of inflation and the expected rate of return a creditor requires. Today, for example, a borrower might be quoted a rate of "prime plus three" for a long term loan. Since prime rates are currently in the area of 10 percent, the quoted rate is 13 percent. At the same time, inflation is running at about 4 percent. As a result, the bank is charging approximately 4 percent to protect itself against inflation and 9 percent as its real return on money.

For preliminary feasibility assessment purposes, it is suggested that a 10 percent real interest rate be used in the analysis. The alternative would be to use nominal rates. This would necessitate the application of projected inflation rates for the various cost and revenue components, and would introduce a whole range of opportunities for errors that are not necessary.

To summarize, the body of assumptions to be utilized in the calculation of unit costs is listed in Table 6-1. If the farmer is already operating a diesel generator, much of this information will be readily available. In the case of a new installation, some analysis of demand, appropriate sizing of units, and related costs will be required. Diesel generator vendors can assist with this information.

The cost items which recur annually are relatively straightforward in the unit cost calculation. The lump sum capital items however, must be converted to annual equivalent amounts. This simply requires a determination of the annual payment which would be required to amortize these amounts over the life of the project. A bank or financing company can readily provide this information or if you have a set of mortgage amortization tables, reference to these will supply the necessary information.

In the absence of these sources, you can calculate the annual payment using this formula:

$$\text{Pmt} = \text{Amt} \div \left[\frac{1 - \dfrac{1}{(1+i)^n}}{i} \right]$$

where,

Pmt = annual sum to amortize the capital cost
Amt = initial capital cost

i = annual interest rate as a decimal fraction - that is 10 percent = 0.10, and

n = amortization period in years

Using the values assumed in the diesel example above, it can be determined that the annualized cost associated with the $53,000 cost of the diesel is:

$$\text{Pmt} = 53{,}000 \div \left[\frac{1 - \frac{1}{(1+0.1)^{20}}}{0.1} \right]$$

$$= 53{,}000 \div \left[\frac{1 - \frac{1}{6.7275}}{0.1} \right]$$

$$= 53{,}000 \div \left[\frac{1 - .14864}{0.1} \right]$$

$$= 53{,}000 \div \left[\frac{0.85136}{0.1} \right]$$

$$= 53{,}000 \div 8.5136$$

$$= \$6{,}225$$

Remember, this annual cost is based on "real" interest rates and therefore does not reflect the actual payments you might arrange on a loan. An actual commercial loan may not be for the same amount, the same term or at the same interest rate. The annual cost calculated above merely represents the "economic equivalent" of $53,000 spent now.

Table 6-2 provides the calculation steps for determining the cost of diesel energy based on the foregoing example. The result of these calculations indicates that the levelized energy cost will be 18.4¢ per kWh used. It is also quite evident that the most significant component of the total cost for diesel energy is fuel purchases. Indeed, these account for 14.3¢ of the unit cost alone ($44,286/310,000 kWh).

Typically, fuel costs would be expected to account for in excess of 75 percent of the total cost. This situation is in marked contrast to electrical supply options which tend to be characterized by high capital costs but low operating costs (i.e., hydro or grid connection).

TABLE 6-2

CALCULATION OF DIESEL UNIT ENERGY COSTS

1. Determine annualized capital cost:

$$\$53{,}000 \div \left[\frac{1 - \frac{1}{(1+i)^n}}{i}\right] = \$6{,}225$$

2. Provide for overhaul fund:

$25,000 ÷ 20 yrs. = $1,250

Note: This solution provides only an approximation. The assumption is that for the first 10 years, the $1,250 is set aside and earns interest. Then, when the $25,000 is actually spent after 10 years, the $1,250 pays the amortization on the shortfall over the next 10 years.

3. Calculate fuel costs:

310,000 kWh/yr ÷ 2.8 kWh/litre = 110,714 litres/yr.

110,714 liters x $0.40/litre = $44,286

4. Sum all annual costs:

Annualized capital cost	$ 6,225
Overhaul fund	1,250
Fuel costs	44,286
O&M costs	5,300
	$57,061

5. Calculate annualized unit cost:

$57,061/yr ÷ 310,000 kWh/yr = $0.184/kWh

The reason for conducting the foregoing estimation of annual costs is primarily to utilize these in comparing alternatives. The same procedures noted above could also be employed to estimate unit costs for grid connections and small hydro development. For example, assume the same farmer investigating diesel generation has also enquired about connection to the provincial electric grid. The buildings are 50 miles from the nearest connection point and the utility company has advised that a suitable transmission line and connecting equipment will have a capital cost of $10,000 per mile. Thus, the total capital cost will be $500,000. Calculating the annual equivalent costs, a value of $58,730 per year is estimated:

$$\$500{,}000 \div \left[\frac{1 - \frac{1}{(1.1)^{20}}}{0.1} \right] = \$58{,}730$$

Furthermore, the utility company quotes a rate of 4¢ per kWh for energy sales. The resulting levelized unit cost associated with this option can thus be estimated as follows:

Annual capital cost	$ 58,730	
Annual energy cost		
(310,000 kWh x 4¢/kWh)	12,400	Total Cost
	$ 71,130	
Levelized unit cost		
($71,130/310,000 kWh)	$ 0.23/kWh	

Obviously, the transmission line option is not as attractive as the diesel option under the circumstances presented here. The diesel energy would come to about 4.5¢ per kWh less than energy from the grid.

6.3.1 Capital vs. Operating Cost Effects

Before leaving this example, one further area of consideration is instructive. There is an essential difference between the diesel and grid options described above and it is best illustrated by examining the effects should the farmer require one more kWh than the assumed 310,000 used above. With the diesel option, the cost of the additional energy would basically be the fuel cost, which was shown above to be 14.3¢ per kWh. With the transmission line in place, the incremental cost on one kWh would be just 4¢.

As a general rule, the incremental, or marginal costs for additional energy will be relatively high for supply options with high operating costs (diesel) and quite low for options characterized by high capital costs (grid connection, hydro).

If the farmer discussed above believed his electrical energy demand was going to increase significantly, the unit costs for grid connection might end up being lower than the diesel costs. Such increases could arise through natural growth, expanded facilities, forming a co-op with other users, or converting some other energy demand (e.g., space heating with an oil furnace) to electric.

An example illustrates the point. Assume the farmer is planning on building a large chicken house which would be heated and lighted 24 hours a day, 365 days a year. It is estimated that this facility would consume an additonal 150,000 kWh per year. Total energy demand would therefore be 460,000 kWh per year. Assuming none of the capital costs are affected, then the levelized unit cost with the diesel option would be:

Annualized capital cost	$ 6,225
Overhaul fund	1,250
O & M cost	5,300
Fuel cost (460,000 kWh ÷ 2.8 kWh/liter x $0.40/liter)	65,714
Total Cost	$78,489

Levelized unit cost:
$78,489 ÷ 460,000 kWh = $0.17/kWh.

For the grid option, unit costs would be:

Annualized capital cost	$58,730
Annual energy cost (460,000 kWh x $0.04)	18,400
Total Cost	$77,130

Levelized unit cost:
$77,130 ÷ 460,000 = $0.168/kWh

As can be seen, this level of demand represents the approximate breakeven point between the diesel and grid options. Further increases in expected demand would tend more and more to favour the grid extension option.

Comparison of Alternatives

Chapter 4 of this manual addresses the analysis of load demand and the cost components associated with small hydro. These components can be divided into capital and operating costs just as has been done with the diesel and grid options outlined above. The analysis of these costs along with the projected energy demand can be utilized to calculate levelized unit costs for a hydro option as well, thereby providing the basis for a direct preliminary comparison between the various energy supply alternatives under consideration.

It must be emphasized that the comparative unit prices developed above may bear little relationship to the actual prices paid by a particular energy consumer. In the early years of the project however, the levelized costs might be close to the actual costs.

Eventually, the effects of inflation and the financing arrangements will cause actual prices to diverge from levelized prices. However, the methodology described above provides a means for removing the effect of these factors such that dissimilar projects can be compared on a common basis at the pre-feasibility stage of project assessment.

More detailed assessment methodologies are described in subsequent sections.

6.3.2 Other Evaluation Considerations

As noted above, the calculation of unit costs is generally the "first cut" in determining project feasibility and comparing electrical supply alternatives.

The examples demonstrated in the previous section were relatively simple because they assumed that only one supply system would serve the end-user. In reality, more than one system would likely be utilized. Generally, diesel generation would serve in either an emergency back-up capacity or as a supplemental peaking supply.

Diesel Back-Up

Emergency back-up would be required where there is a need to have some minimal level of power if the primary source is out of service. This situation arises where freezers are required to preserve food, heat is required, some minimal lighting is required, medical equipment is in use, etc. In other words, emergency power is necessary wherever the ramifications of being without power supplies are serious enough to warrant provision of back-up. In very remote areas, it is probable that some back-up will be necessary because it could take some time to repair the primary source if it is out of commission due to accidents or breakdowns. Slides can take out transmission lines, intakes could be blocked on a hydro generator, diesels could breakdown and so on.

These circumstances make it is necessary to include the capital cost of a small back-up diesel generator in the total costs of the system being evaluated.

The other area where diesel generation is often applied is in the role of planned, supplemental peaking power along with a small hydro installation. In the emergency, back-up role discussed above, any operating costs for the diesel are not necessary to be included since the expectation is that it would not actually be used.

In the peaking role, however, this is not the case. Here, the expectation is that the diesel will supply all demand which exceeds the supply available from the small hydro facility.

The sizing of the necessary diesel will depend on the peak demands identified through the analysis of your load requirements and the hydrological investigations which will indicate the firm power available from hydro. A common situation will be that load peaks occur in the winter, as heat and light demands are greatest, while power from the hydro plant is relatively low because of low water flows. The difference must be made up by the diesel.

In order to calculate the levelized unit costs associated with a combined hydro/diesel option, you need to estimate the amount of energy which would be supplied by each. The relevant capital and operating costs for both must also be compiled.

Load Management

Another area of consideration in the preliminary economic analysis is the managing of load to optimize the economic results. As noted earlier, for example, if a supply option is characterized by high capital costs, the unit costs will be reduced if the load increases. As a result, it will be to your benefit to seek maximum utilization of such systems.

A hydroelectric development costs the same whether 50 percent of its potential power is utilized or 100 percent. Obviously, the unit price of energy under these two circumstances will be quite different, however. A similar effect is observed in the relationship between peak and average demands.

Basically, if peak demands are far greater than average demands, to design capacity to meet the peaks may be quite inefficient, if by doing so, your capital costs increase significantly. Figure 6-1 illustrates the situation. Graph (a) depicts a demand curve that is quite peaked, with peak demand being more than twice the average demand. Graph (b) illustrates a load curve with a more modest peak. Average energy requirements are the same in both graphs.

The impact of these different demand curves is illustrated when supply costs are considered. Suppose a hydro electric facility can be constructed on a stream and that it can be designed to provide a firm power output of 900 kW or 600 kW. The former is estimated to cost $1.5 million while the smaller unit will cost $1.0 million. With load curve (a), the peak would be met by the 900 kW installation, but only about 40 percent of the available power would be utilized. All of the available power in the shaded area above the demand curve would simply be wasted. This situation obviously will lead to very high unit costs for the energy which is used.

If your power demand curve is similar to that shown in curve (a), you may be able to manage loads to achieve a demand curve similar to graph (b). If so, the economics of the project will improve substantially. This can be done by shifting some energy consuming activities to non-peak demand periods. Now, the $1.0 million development will be adequate and approximately 60 percent of the available power will be utilized. Obviously, the unit costs will be substantially lower under these circumstances, as indicated in the following calculations:

Case (a)

Installed capacity	900 kW
Average demand	400 kW
Capital cost	\$1.5 million
Annual energy available (900 kW x 8760 hrs.)	7,884,000 kWh
Annual energy used (400 kW x 8760 hrs.)	3,504,000 kWh
Utilization Factor (3504/7884)	.44
Unit cost (10% int., 30 yrs.)	

$$\frac{(\$1{,}500{,}000) \div \left[\dfrac{1 - \dfrac{1}{(1 + i)^{30}}}{i}\right]}{3{,}504{,}000 \text{ kWh}} = 4.5¢/\text{kWH}$$

Case (b)

Installed capacity	600 kW
Average demand	400 kW
Capital cost	\$1.0 million
Annual energy available	5,256,000 kWh
Annual energy used	3,504,000 kWh
Utilization factor	.67
Unit cost	

$$\frac{(\$1{,}000{,}000) \div \left[\dfrac{1 - \dfrac{1}{(1 + i)^{30}}}{i}\right]}{3{,}504{,}00 \text{ kWh}} = 3.0¢/\text{kWH}$$

Obviously, the lower capital cost and higher utilization factor in Case (b) is preferable since it results in a unit cost about 33 percent lower than case (a).

As indicated, load management can offer obvious benefits. In most circumstances, however, some peak demands will be unavoidable. In many cases, it may simply be more economic to not design for peak loads. Suppose for example, in case (b) above, that a third hydro development option could have an installed capacity of 400 kW and a cost of \$700,000. Under these conditions, the utilization factor would be in the area of 95 percent and the unit cost would fall to about 2.2¢/kWh.

In this situation, the five percent peak demand would be met by diesel. If the cost of this diesel energy is say 15¢/kWh, then the weighted average unit price is still more attractive than if a larger hydro installation, which is sized to meet peak demand, is constructed. The resulting unit price in this scenario is ((.95 x 2.2¢) + (.05 x 15¢)) = 2.8¢/kWh.

Determining appropriate project sizing requires substantial effort. Constraints on the range of options which are feasible will be imposed by the engineering and hydrology studies. Application of the levelized unit costs techniques described here, however, will provide a useful tool for narrowing the range of alternatives.

Energy Conservation

A final area of concern in the preliminary economic analysis involves the question of the costs of energy conservation against the costs of a new electrical generation project. Earlier, it was stated that by increasing the average load on a small hydro facility, the unit costs of the energy will decrease. One of the ways mentioned to increase load demand involved converting space heating from oil-fired furnaces to electric elements.

Adding load is not necessarily economically efficient if there are serious inefficiencies in the demand pattern, however. Consider the following extreme case. The owner of a building complex is considering development of small hydro to heat and light the buildings. These end-uses currently consume the equivalent of 200,000 kWh annually, with about 75 percent of that amount devoted to heating. The preliminary analysis of a suitable hydro development to meet this demand has revealed that the expected unit cost will be 5¢/kWh.

Current costs are 15¢/kWh to generate the electricity used for light with diesel. Space heating is provided by oil furnaces. Heating oil costs 40¢/litre and has an energy content of about 10.5 kWh per litre. The furnaces have a combustion efficiency of 55 percent so the net cost of an equivalent kWh for heating is 6.9¢/kWh.

As a result of the foregoing analysis, the building operator is convinced that the small hydro development is an attractive investment. A friend, however, looked at the situation and discovered the following. For a capital cost of only about 5 percent of the hydro cost, insulation could be added to the attic of the building, automatic setback thermostats could be installed, furnaces could be adjusted to achieve 70 percent efficiency and double-glazed windows could be installed. As a result, the unit cost for heating would drop to 5.4¢/kWh and overall heating demand could drop to 50 percent of the demand before conservation. Furthermore, it is discovered that by using fluorescent lights instead of incandescent bulbs, turning off appliances when not in use and reducing the temperature setting on the electric hot water heater, electric consumption can be reduced by 20,000 kWh per year.

Also, as a result of the reduced demand caused by these conservation measures, the predicted unit cost from the hydro development would rise to 9.5¢/kWh. Thus, the building operator has three choices:

1) No conservation, install hydro
   200,000 kWh x .05 = $10,000/yr.

2) Conservation, install hydro
   105,000 kWh x .095 = $10,000/yr.

3) Conservation, no hydro
   75,000 kWh x .054 = 4050

   30,000 kWh x .15 = 4,500
   $8,550/yr.

The foregoing example is extreme but clearly illustrates the point. New generation, even if it is less costly than the present supply, will not necessarily provide greater economic efficiency if the consumption of that energy is itself wasteful and inefficient.

6.4 DETAILED ECONOMIC ASSESSMENT

Assuming the preliminary feasibility analysis and estimation of energy unit costs provided adequate encouragement to continue, more detailed engineering, hydrology and demand analysis tasks will have been undertaken. As a result, cost estimates will be more refined, units will have been sized and the available energy will have been calculated.

At this stage then, it is appropriate to conduct a more rigourous analysis of project economics. The technique employed is known as discounted cash flow (DCF) analysis. (For public sector financed projects, DCF methods are modified slightly, and are often referred to as benefit - cost analysis.)

DCF analysis is used to screen projects to insure they meet minimum economic criteria and to rank those projects which satisfy the minimum criteria so that the "best" alternative is taken. The methodology takes explicit recognition of the "time value of money" by considering that dollars expended or received now are more valuable than dollars expended or received several years in the future.

The underlying value of money is dependent on the notion of "opportunity costs." An illustration will help explain. An individual has $1,000 of wealth, or capital. He may invest it in a deposit certificate at a bank and earn 10 percent per year on this capital. This would be considered a relatively non-risky investment. The same individual could invest the $1,000 in a small hydro project. By doing so, he gives up the 10 percent return he would have had if he had the deposit certificate. Thus, the "opportunity cost" of investing in the hydro project is what would have been received from the next best foregone opportunity; in this case, the bank deposit. With this perspective in mind, you would only invest in the hydro project if the expected return is greater than 10 percent. DCF analysis provides a formal framework for determining if this is the case.

Basically, discounted cash flow analysis merely involves the comparison of cash outflows with cash inflows. If the latter are greater, then the project has positive economic benefits. However, since these cash flows will occur at different times over the life of the project, they must be adjusted in recognition of the time value of money.

In most cases, the hydro development will be assessed in the context of: "Is hydro development preferrable to continued reliance on diesel generation?" Under these circumstances, the principle cash flows are the initial outlay for construction of the hydro facilities, followed by cash inflows which are represented by the diesel costs avoided, less any operating costs for hydro. Taxes and water rental payments may also represent significant cash flows.

Two simultaneous tasks must be accomplished: estimate the cash flows and establish the timing of these flows. The timing problem involves identifying all the cash flows which are expected to occur in each year. It is especially critical to first address the issue of "useful life".

Timing Considerations

Useful life is the shorter of the expected lifetime of the major components of the hydro facility and the expected lifetime of the end-use activities. For example, a hydro plant proposed for a logging camp and sawmill may have an expected lifetime of 35 years. However, the trees to be harvested in the area will only sustain logging and sawing activities for 20 years. Therefore, the "useful life" of the hydro plant is 20 years.

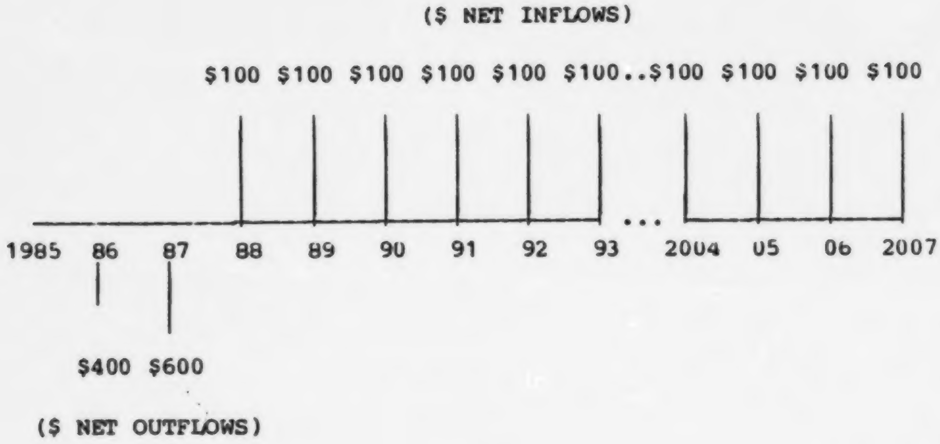
A second important timing consideration involves assigning the timing of project start-up activities. The start and length of the construction period will influence the timing of cash outflows, and will also determine the timing of when cash inflows (that is, electricity) will commence.

The best way to address these timing issues is through the construction of a time-line. On a worksheet, simply draw a line and divide it into annual segments. The length of the line will be established by your assessment of useful life. Figure 6-2 illustrates a time-line for a project that is expected to have a useful life of 20 years, a construction period of two years and a construction start in 1985.

Figure 6-2 indicates the net sums of all cash flows in 1985 and 1986 are negative and are therefore net outflows. This is expected since the activity during this period is construction. Thereafter, the cash flows are positive since the diesel costs avoided are greater

FIGURE 6-2

HYPOTHETICAL PROJECT TIME-LINE


($ NET INFLOWS)
$100 $100 $100 $100 $100 $100..$100 $100 $100 $100
...
1985 86 87 88 89 90 91 92 93 2004 05 06 2007
$400 $600
($ NET OUTFLOWS)

than the costs of operating the hydro facility. These cash inflows occur during each year of the 20 year useful life.

Estimating Cash Flows

The next step is to estimate the actual magnitude of the cash flows and to assign them on the time-line. First, allocate your capital costs to the construction periods. For example, for a $1.0 million facility, you might determine that about $400,000 will be spent in 1985 and $600,000 will be spent in 1986. Remember to include engineering, construction supervision, testing and start-up, and any other front-end costs which will be incurred during the construction period. From these costs, you should deduct any government grants, investment credits or tax reductions that may be available so that the amount recorded on the time-line is the net amount for the period.

Next, you must calculate the annual inflows during the operating period. For simplicity's sake for the moment we will assume that demand is not expected to grow over time and that real price changes are not expected. The following is a checklist of the items which would typically be included in the annual cash flows:

Item	Impact On Cash Inflow
Avoided capital cost of diesel generators	+
Avoided annual maintenance of diesels	+
Avoided fuel purchases for diesels	+
Avoided overhaul & replacement of diesels	+
O & M costs of hydro facility	(-)
Replacements of hydro components	(-)
Income & property taxes	(-)
Water rentals	(-)

Assume that the capital costs of the diesels have already been incorporated in the estimates for the 1986 net cash flow and that major replacements are not anticipated. Then, the annual cash flow for periods after construction might be calculated as follows:

Item	Amount
Annual maintenance of diesels	$ 20,000
Fuel purchases for diesels	140,000
Hydro O & M costs	(30,000)
Taxes	(20,000)
Water rentals	(10,000)
Net annual cash inflow	$100,000

On the time-line shown in Figure 6-2, the net inflow of $100,000 for each year for 20 years is indicated. Unfortunately, in practice, the cash flow will not generally be the same each year because of certain complications arising from the calculation of taxes.

Taxable income will usually not be the same as net income because in Canada, capital cost allowances (CCA's) on depreciable property serve to reduce taxable income. CCA's are calculated on a declining balance basis, that is, the allowance in one year is deducted from the balance to provide a new capital cost base for the subsequent year.

Unless you are familiar with the calculation of CCA's, their tax shielding effects and the present value of tax shields, you should seek the assistance of your accountant in estimating your annual cash flows. Some hydro developments may qualify as energy conservation projects which merit CCA's at a 50 percent rate under provisions of Class 34 of the CCA schedule. Otherwise, the rate will probably be 20 percent. You will need a ruling from Revenue Canada as to which class is appropriate for your project.

Calculating Summary Investment Criteria

Once the cash flows have been assigned to each period, it is necessary to manipulate them into a form which will indicate the attractiveness of the development. One summary description of the investment is known as "simple pay-back period". This is merely a calculation of the time period required before the original investment is recovered. Using the data from the time-line in Figure 6-2, simply add the positive cash flows in sequence until the sum equals or exceeds the original investment of $1.0 million. It is readily seen that the pay-back period in this case is 10 years ($1,000,000/100,000 = 10). This measure provides a simple rule of thumb but it tells you nothing about the return on your investment, the value of the cash flows beyond the pay-back period or the time value of these cash flows.

A more sophisticated analytical approach involves the calculation of the net present value of the investment. This is done by summing all of the cash flows after they have been adjusted for their time value. The adjustment, or discount, factor is $1/(1+i)^n$; where i is the required return on investment and n is the period in which the cash flow takes place.

A set of financial tables which provides present value factors will do the calculation for you. Otherwise, you can calculate it yourself if your calculator can raise numbers to power of "n" (that is the number times the number, "n" times). For example, $(1 + 0.1)^3$ is the same as $(1.1 \times 1.1 \times 1.1) = 1.331$.

If the minimum required rate of investment is 10 percent, then the cash flows from Figure 6-2 can be used to calculate a net present value as shown in Table 6-3. The result is a negative $156,000. It should be noted that 10 percent is a relatively high "real" discount rate since interest rates have historically rarely exceeded inflation by this amount. A more realistic rate might be about six

TABLE 6-3

CALCULATION OF NET PRESENT VALUE

Year	Net Cash Flow	DIVIDED BY	Discount Factor for interest for 10% $(1+0.1)^n$	EQUALS	Present Value
1	(400)		(where n= 1) = 1.100		(364)
2	(600)		(where n= 2) = 1.210		(496)
3	100		(where n= 3) = 1.331		75
4	100		(where n= 4) = 1.464		68
5	100		(where n= 5) = 1.611		62
6	100		(where n= 6) - 1.772		56
7	100		(where n= 7) = 1.949		51
8	100		(where n= 8) = 2.144		47
9	100		(where n= 9) = 2.358		42
10	100		(where n=10) = 2.594		39
11	100		(where n=11) = 2.853		35
12	100		(where n=12) = 3.138		32
13	100		(where n=13) = 3.452		29
14	100		(where n=14) = 3.797		26
15	100		(where n=15) = 4.177		24
16	100		(where n=16) = 4.595		22
17	100		(where n=17) = 5.054		20
18	100		(where n=18) = 5.560		18
19	100		(where n=19) = 6.116		16
20	100		(where n=20) = 6.728		15
21	100		(where n=21) = 7.400		14
22	100		(where n=22) = 8.140		13
Net Present Value					-156

percent. If this discount rate is used, the next present value becomes a positive $110,000. The interpretation of a positive net present value is as follows:

You recover your initial investment outlay, you earn the required rate of return on that investment (in this case six percent real) and you have an additional gain in wealth equal to the amount of the net present value (that is, $110,000).

When evaluating your project, if the net present value is positive, then it can be said that you will be better off economically with the project rather than without it.

Another measure used to screen and rank possible projects is the internal rate of return (IRR). The IRR is simply the discount rate which will yield a net present value of zero. Without a computer or financial calculator, it is cumbersome to determine the IRR because it requires a trial-and-error process of simply using different discount rates until the $0 NPV is found. For the example discussed above, since the NPV is positive at a discount rate of six percent, we know the IRR must be greater than six percent. As it turns out, the actual IRR is about 7.55 percent.

For government sector project sponsors, it is common to calculate a benefit-cost ratio for projects. This ratio is the present value of project benefits divided by the percent value of project costs. Using the six percent discount rate, the project above is seen to have benefits of $1,021,000 and costs of $934,000 to yield a B/C ratio of 1.09. Projects are considered economically feasible if the B/C ratio exceeds 1.0.

The calculation and interpretation of these summary economic evaluations can be quite complex. In many cases, you may find it appropriate to secure the assistance of an accountant or financial consultant for these tasks.

6.5 FINANCING ALTERNATIVES

Since most hydro developments will entail substantial front-end capital costs which must be funded, it is likely that there will generally be a mix of funding sources involved. The major potential sources of project financing include: owner's equity, commercial loans, bonds, financial leases, government grants and various forms of equity raised from arm's length investors (i.e., limited partnerships or stock offerings).

The most common arrangement will probably involve your own equity and debt in the form of a long-term loan or mortgage. This situation is not much different than the purchase of any other property or equipment and the success of this arrangement will turn on convincing your banker of the viability of the project. The analysis discussed in the previous section will be instrumental in this respect. The bank loan officer will be most interested in your documentation of the net savings expected from the project since this will determine your ability to cover the loan payments.

Bonds are another form of long-term debt but access to bond markets is generally limited to large corporations and governments. Bond market funds are usually available at a lower rate of interest than loan funds, but the size of the bond issue usually has to be in the multi-million dollar range to justify the issue costs. These fees and other expenses can be from two to three percent of the total borrowed.

Leasing arrangements can be advantageous in certain circumstances. Basically, a financial company buys the equipment and turns around and leases it to you. Lease payments are set to cover both the principal and interest on the equipment, similar to a loan for the same amount. The advantage to you as the developer is that the full amount of the lease payment is tax deductible rather than just the interest portion of the payment. You would not receive capital cost allowances, however, since you are not the owner of the equipment. The finance company would have the advantage of these CCA's.

Leasing arrangements of this type can be quite useful and you may be able to avoid the need for some of the front-end capital which would otherwise be required. These contracts must be structured very carefully, however, to avoid unwanted tax consequences. A reputable leasing company or financial advisor can assist you in pursuing leasing options.

Beyond the funding sources noted above, a wide range of structures can be contemplated which entail equity participation by others. For example, limited partnerships can be sold to investors who can take advantage of the flow-through of tax deductions (soft costs, accelerated depreciation) and who also look forward to capital gains in the future. These entities operate much like a real estate development syndication. Also, certain potential hydro developers may be in a position to issue stock to raise funds. The intricacies of these kinds of funding opportunities, however, are beyond the scope of this manual.

A final potential source of funding may be government grants. The principle program that is currently in place is the ENERDEMO program administered by Energy, Mines and Resources Canada. This program can supply a portion of the capital funding for eligible projects. You should contact EM&R for details of the assistance which may be available.

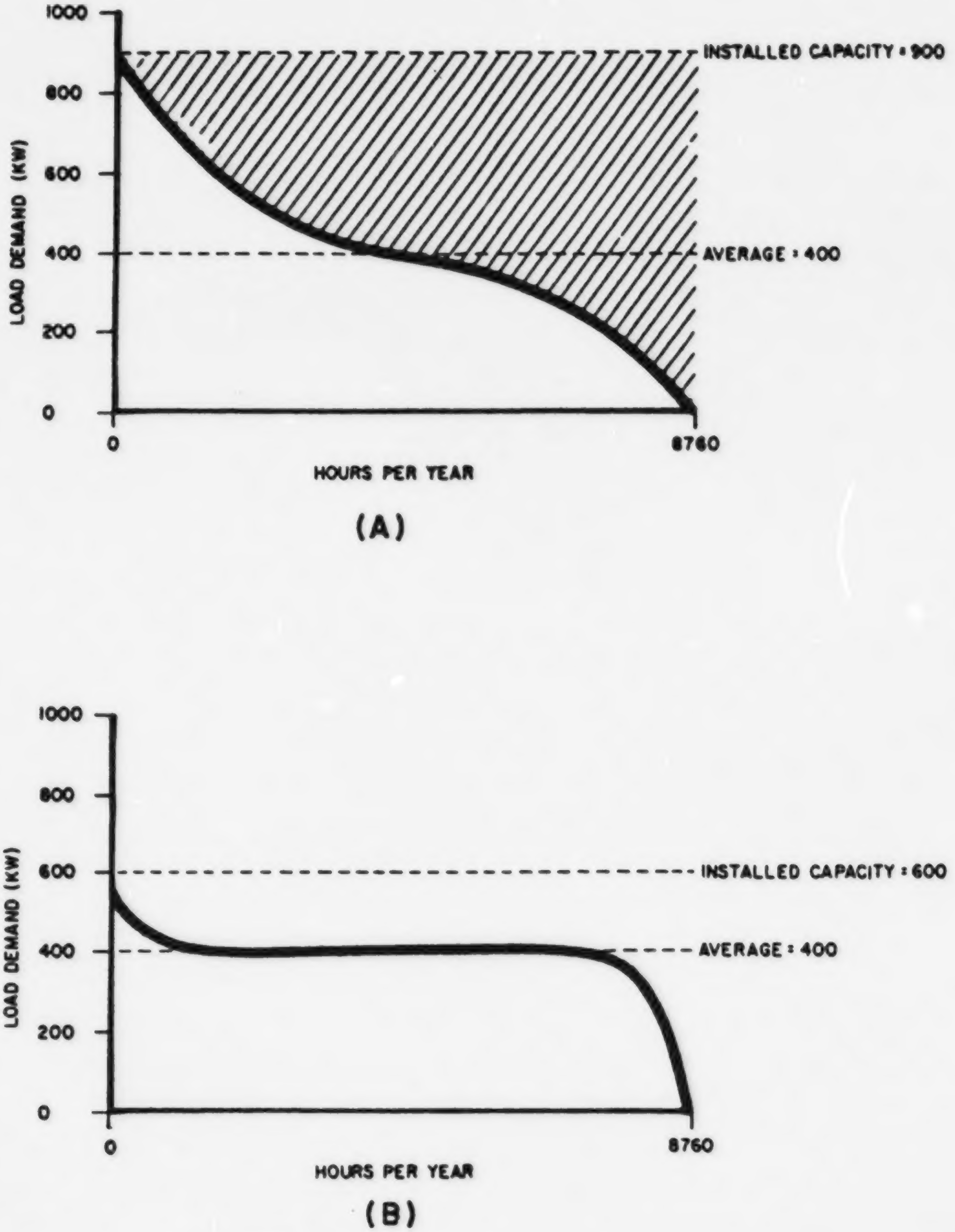


FIGURE 6-1

DEMAND AND
CAPACITY RELATIONSHIPS

ACRES

7. GETTING STARTED

7.1 GENERAL

In the earlier chapters you have been instructed in many of the design steps necessary to prepare for the construction of a hydro power plant. In this chapter you will be informed of the many logistical steps necessary to carry through with the project once designed, not only to "get it started" but also to "see it finished".

7.2 PROJECT SCHEDULING

7.2.1 Planning Activities

As a first step we will assume that you have an idea of a certain location which may be suitable for a small hydro project, but as yet have not done any work on it. A chart similar to Figure 7-1 is used to prepare a list of activities based on the reference information in the Glossary. The pre-construction activities as shown do not have to take place in the exact order indicated, but as a general rule the earlier that planning work is initiated the better. However, all of the preparatory stages should be completed prior to awarding contracts. Although some projects can proceed without doing all the steps in order, you take the additional risks of possible delays or refusals.

7.2.2 Construction Schedule

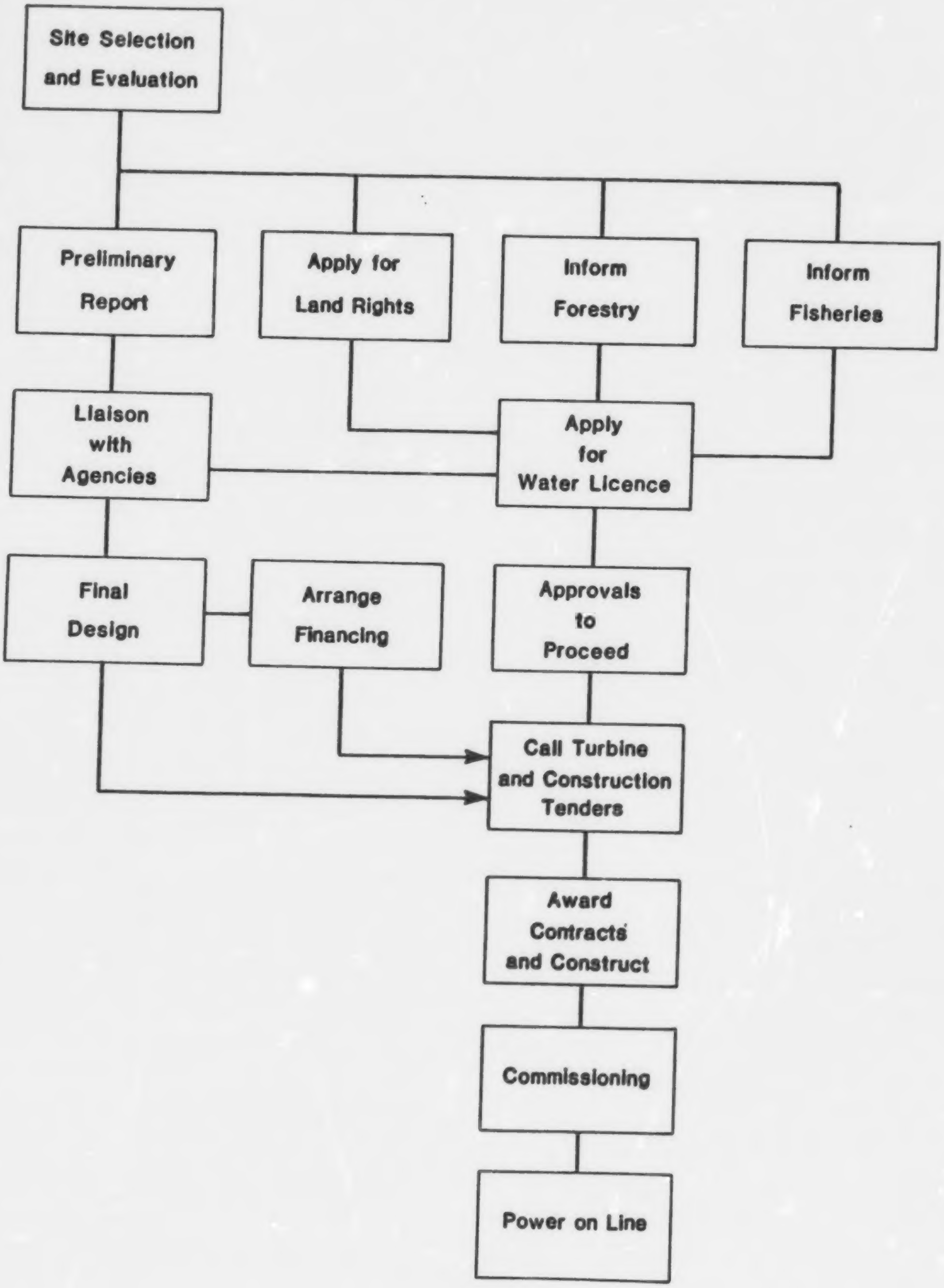
General

While Figure 7.1 acts as a convenient checklist of activities it does not provide detailed timing information necessary to plan a project. For detailed information a bar chart similar to Figure 7.2 is used. With the use of the bar chart a critical path develops, based on the least time to complete the project while considering the precedence of the activities. The preparation of the bar chart usually will not be possible until enquiries have been made to agencies, contractors and suppliers; and some design work has been done. Once these activities are completed, the longest duration items are entered first, then shorter duration activities are entered consistent with the requirement for the completion of some activities before others can begin.

In most hydro power projects the following general considerations will apply:

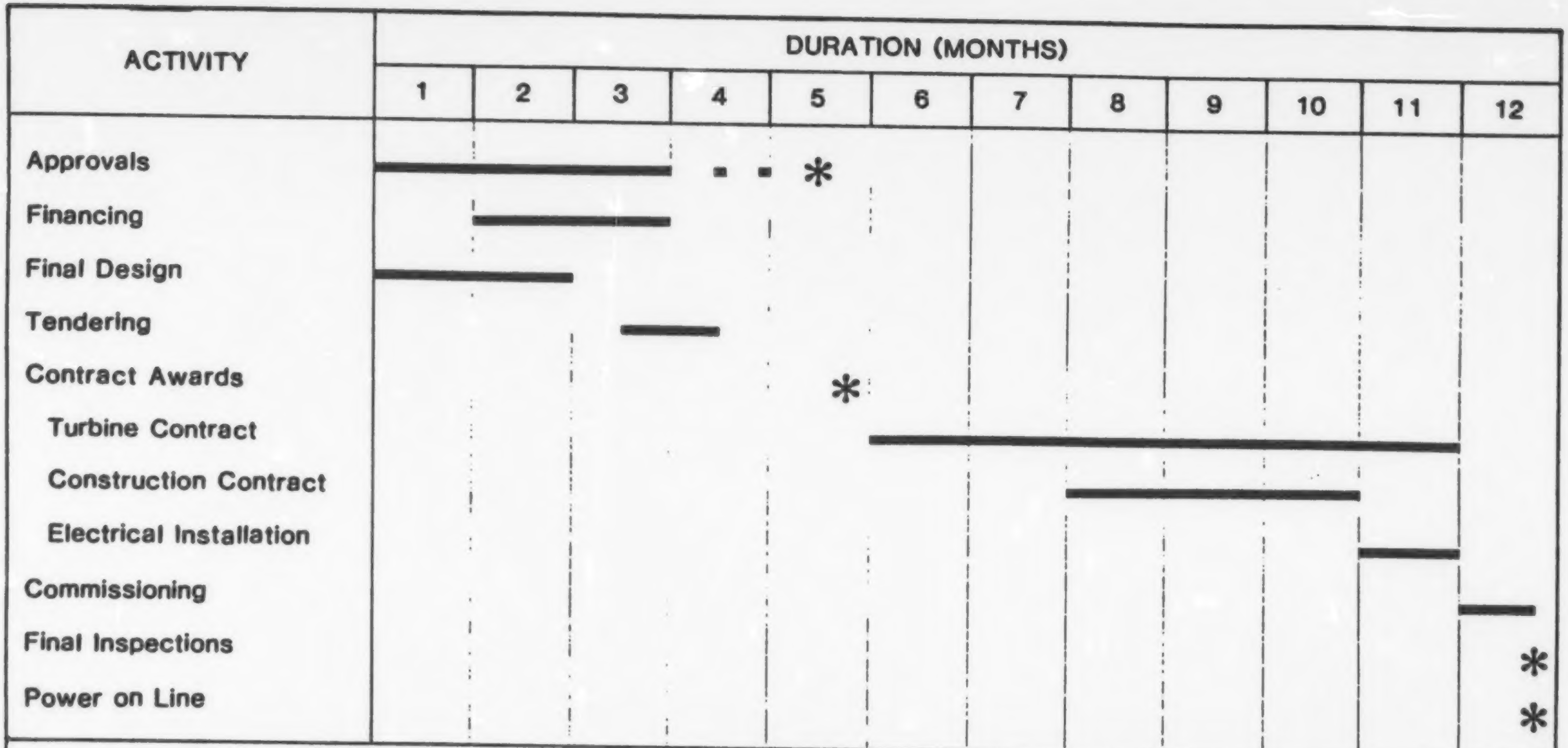
1. The approvals process is the most uncertain duration, ranging from a minimum of three months to as long as two years for complicated projects.

2. Turbine/generator/control delivery is usually the longest duration construction item, but is also reasonably predictable. Many other construction activities can take place concurrently.


Site Selection and Evaluation
Preliminary Report
Apply for Land Rights
Inform Forestry
Inform Fisheries
Liaison with Agencies
Apply for Water Licence
Final Design
Arrange Financing
Approvals to Proceed
Call Turbine and Construction Tenders
Award Contracts and Construct
Commissioning
Power on Line

ACTIVITY PLAN

FIGURE 7.1



NOTE: Schedule may need adjustment to suit local conditions of weather, streamflow, fish activity, availability of transport and availability of labour.

CONSTRUCTION SCHEDULE

FIGURE 7.2

3. Financing arrangements and design should be done before calling tenders for turbine and construction.

4. There is no set preference for the construction order of the intake penstock and powerhouse unless governed by local conditions.

5. Electrical work and all other phases of a project should be done prior to turbine installation to allow for testing and commissioning by the manufacturer's representative.

The basic precedence of key activities is also influenced by many constraints which arise because of the location, time of construction and the unexpected.

However, prior to reaching the point of construction, most of the project approvals should be obtained. These have their own sets of potential delays.

Approvals

The approvals process can be one of the longest duration activities in the process of developing a small hydro project, but it need not be. Most agencies involved in the approvals process from government departments through to financial institutions have routine guidelines which are followed, so you should ensure that there is sufficient information presented in order to expedite the process. The information needed will include plans, hydrology, power estimates and other requirements as determined on an individual basis.

Once into the process, it is important for you to follow your application along, preferably by establishing phone contact with the official involved in the approval. This will result in good liaison being established, and an open line of communication with the approving agency. Although you can do little to improve the speed of internal office procedures at the approving agency, you can assist the process by responding quickly and thoroughly to any additional information requests.

Time of Construction

The time of year in which a project is constructed can influence the pace and quality of work. From November through to March in most areas of the province a project can be hampered by high rainfall or snowfall, fewer hours of daylight, and sub freezing temperatures. Besides the obvious physical difficulties of work in adverse conditions, the quality of the work can be affected, especially if proper precautions are not taken to keep fresh concrete warm during sub freezing weather and to follow prescribed construction methods requiring heat.

Other influences of winter weather include high water during freshets, which may hamper work in the intake area. Transportation services to isolated sites are more unreliable in winter, and may lead to delays and expense if critical items must be shipped in. The time of construction is also affected by fisheries constraints, which may limit instream construction activities to certain periods of the year.

Location

The location of a project has a significant bearing on the timing of the work. Any of the conditions above can be worsened if a project is remote, especially if the work is contracted and the contractor faces extra costs in mobilization and delays. Access to the site itself may prevent any form of winter construction.

Materials Supply

Materials supply is one of the most important considerations of the overall project. Although more detailed discussion is provided in Section 7.3, the importance of materials availability is worth mentioning in this section. Whether provided by you or the contractor, the materials must be on site to allow the work to progress, as most projects have a relatively small amount of work (such as clearing and earthwork) which can proceed without materials. The main point to emphasize is, that if you choose to supply the contractor with material, which you may be able to supply at lower cost, you should also be certain of the delivery dates of such materials to avoid extra costs due to delay.

The best approach to reduce the cost of delay is to have the work proceeding on several fronts at once; if a delay occurs in one area, say due to high water at the intake, work can be shifted to the penstock or powerhouse until the reason for the delay is overcome. This is most easily achieved in the early stages of construction, but as various sections of work are completed the activities available narrow so that work progress on each item is more critical. However by this time the job has also simplified, leaving fewer details to worry about. Additional means of reducing problems in a project which is contracted, are discussed in Section 7.3.

Time Estimates

One of the most difficult tasks in construction scheduling, especially for an inexperienced developer, is the estimating of activity durations in constructing the hydro power project. This is complicated by the nature of the subject: there are so many variables which are dependent on the actual site conditions and design. Other factors may apply if the work is constructed on a do-it-yourself basis, as opposed to a contractor basis. In this section, some rough estimates of durations will be provided, along with the factors which will change the estimates.

The estimates are based on using a three man crew and one piece of construction equipment of each type required for a 50 kW to 100 kW project.

Intake: One to two weeks for the simplest type. If diversions extensive concrete work are required, or it access is difficult, duration could be four to six weeks.

Penstock: (Buried PVC, no bends) 50 metres to 100 metres per day. Allow additional time for above ground, supported and anchored pipe. Allow further time for frozen ground, difficult digging and lightweight machinery. If there are significant amounts of manual work and/or steel welding, times will greatly increase unless the labour force is increased.

Powerhouse: Concrete substructure: about one week to two weeks. Superstructure (wood or steel frame) one week to three weeks. Allow additional time for powerhouse crane, concrete block building, long tailrace and other deviations from a simple structure.

Electrical: Powerhouse wiring: one week to two weeks. Pole Line: Allow one day per pole span.

Turbine installation and commissioning: one week to two weeks. Allow extra time if all other components of the project are not completed.

In general "float" time should be allowed between activities to allow for unexpected delays and prevent conflicts with an area of work infringing on another.

Updating Time Estimates

Once the schedule is established it must be followed to keep control of the project. Where variations occur, you must update the schedule, look for areas of conflict and revise the starting times of other activities accordingly. In addition to construction activities, you must ensure that times governing your approvals and financing continue to be met.

7.2.3 Checklist of Activities

At various stages in the design and construction process you should consult a checklist such as the one shown below, to assure that all necessary steps have been taken to avoid costly delays later. The activities can be summarized in the categories of Design, Approvals, Materials and Contracting.

Design

Project Size: Loads, potential growth and optimum plant size

Hydrology: Minimum and maximum flows, and average energy available.

Intake: Water levels, air vent, main shut off, stop logs or equivalent, trash rack, sediment removal, freeze protection, hydraulic entrance conditions.

Penstock: Pipe size, pressure ranges, water hammer design, depth of burial, freeze protection, above ground supports, domestic or fire flow connections, bedding material, drainage of penstock.

Powerhouse: Interior layout, roof snow load, penstock terminal anchor block, interior drainage, windows, crane, tailrace hydraulic capacity, door sizes.

Electrical: Powerhouse interior: lights, heater, ventilation, main breaker sizing, control of machinery, linkage with existing or backup power system, metering, monitoring, remote control, protection systems. Sizing of powerline and transformers.

Turbines: Generator and Equipment: Machine specific speed, linkage to generator, governing, setting above tailwater, net head, speed of gate closure, main shut off valve, anchorage, ease of services, bearing type and rating, protection for overspeed and high bearing temperature.

Approvals

Secure Land Tenure: ownership, easement, right of occupation, special use permits etc.
Water Licence
Tree Cutting Permits
Fisheries Approval
Environmental Concerns
Financing of the Project
Public information (if required)

Materials

Pre-order long delivery items
Secure local sources of material, such as concrete aggregate and pipe bedding.
Coordinate shipments with available transportation carriers
Protect materials in shipping, handling and storage.

Contracting (Also see Section 7.3)

Tender documents
Tender advertisements
Tender evaluations
Construction schedule to suit weather, materials supply, fisheries concerns and other contractors
Progress payments
Inspection
Final electrical inspection
Commissioning and testing
Holdbacks

7.2.4 Planning Tips

With the preceding information absorbed you should be able to start planning your project, using real times and activities. However, there are some additional points which should be mentioned to further enhance the project:

1. Try to plan everything in advance and make contacts early, especially to get approvals.
2. Use realistic time estimates. Maintain float times to allow for unexpected delays.
3. Avoid cash flow difficulties and excess interest costs by trying to schedule the work so that most of the cash flow comes towards the end of construction.

7.3 PROJECT CONSTRUCTION

7.3.1 General

Once a project has been planned and approved, the major task remaining is to construct the project. Depending on the size of the project, you may choose to do much of the work yourself or have the work done under contract. In either case you should be well prepared both technically and legally to undertake the work.

The technical preparation could be substantially completed following the steps in this manual but other action, particularly that involving contractual matters will be important if you hire others to do the work. These forms of contract are discussed in the following sections.

7.3.2 Contract Organization

Types of Contracts

The final decision to be made if you decide not to do all the work yourself, is the type of contract which would be most suitable to your needs. Some options and their respective merits include:

1. Day Labour or Cost Plus: You hire a contractor or individual labourers at fixed hourly rates and agree to pay for all hours worked. This is probably the most flexible contract arrangement, because little in the way of detailed engineering or contract documents is required. However, you take the risk that if the work takes longer to do than expected, for whatever reason, you are liable for the full cost.
2. Unit Price: A unit price contract is a flexible document in which the bid prices are based on estimated quantities, while the contract payments are based on actual quantities. This contract has the effect of fixing the final cost prior to construction, but there is risk that if the quantities exceed the estimate, the cost will be greater than anticipated. Depending on the nature of the quantity and the way that the

Contractor has weighted his prices, the increase could be substantial. There is also the requirement to verify the quantity measurements.

3. Lump Sum: A lump sum contract specifies a body of work to be done without regard to quantities. The Contractor must rely on his own interpretation of quantities to derive his prices. While this type of contract is very simple to arrange if all goes well, if problems arise or errors are found in the drawings or in the definition of the work, the contractor may have justification for a substantial claim.

4. Stipulated Sum: This form of Contract combines aspects of a lump sum and a unit price contract. The contract units are for entire pieces of work, such as the intake, penstock or powerhouse, but there is provision for variations by including values for adding or deleting quantities, such as earthworks, pipe, metalwork, concrete and reinforcing. In addition, hourly rates are provided for labour and equipment. This form of contract can limit the amount of extra work involved and provide a simple means of reducing quantities, if required. It still requires on site measurement if there are variations.

Form of Contracts

Once the type of contract has been selected, it remains to organize the contract document into a form which will be clear comprehensive and equitable to both parties. Although a contract can be set down in one page, experience has shown that a short document cannot cover all of the potential problems which are likely to occur. In this section we will describe a CCDC (Canadian Construction Document Committee) Contract, which is a medium length contract document well recognized in the industry. You may use the contract as an example, or simplify it if appropriate. Copies of contracts are available at nominal cost from the Almagamated Construction Association, 2675 Oak Street, Vancouver, 736-6311.

1. Introduction: Matters of mutual understanding such as the governing laws, lawful money, location, type of project, and time constraints are set down.

2. Form of Tender: A document within the document, the Form of Tender is submitted by contractors with their offer to build the project as described in the documents. It contains blank spaces for filling in a price summary, Schedule of Unit Prices, Schedule of Alternative Prices, Schedule of Addition/Deletion Prices and Schedule of Labour and Equipment rates. In addition, the contractor provides a summary of his relevant work experience and a time schedule which he intends to follow.

3. Contract Forms: When a successful tenderer is chosen most of the information from the Form of Tender is entered into similar forms in Section 3. There are also samples of Bid Bonds and Performance Bonds which may be used, as described below. There is also space for both parties to sign and seal the Contract.

The Contract General Conditions are at the end of Section 3. In the CCDC forms, these comprise 39 statements covering job standards, such as insurance requirements, safety regulations, method of payment, as well as a number of remedies each party has if the other party fails to live up to his side of the contract.

4. Supplemental General Conditions: In this section you have the opportunity to waive any of the preceeding conditions or clarify any other points unique to your project. One point which should usually be added is that "the contractor shall provide the owner with any documentation necessary for the owner to secure federal and provincial sales tax rebates". Materials which are exempt from such tax, such as pipe, valves, turbine and electrical generation equipment (up to the transformer) may receive rebates of five percent to nine percent of their tax included purchase price.

5. Detailed Specifications: This section contains the actual job description for each unit price item required (e.g. intake, penstock powerhouse) and outlines the method of construction to follow:

   Scope: Describes what work is included in the item.

   Materials: Describes the grade and quality of materials to be used for the various components.

   Construction: Describes the workmanship to be utilized in the item.

   Measurement and Payment: Describes how the item is measured (by units or lump sum) and how the units are paid for. Reference is made to the prices in Section 3.

6. Drawings: Reference drawings should be provided to explain all facets of the project. As changes are made, revisions shall be issued. The drawings are subsequently marked in the field to record construction changes and revise as-built drawings.

Division of Contract

Your final decision regarding contracts involves dividing the work. The range of divisions can be as follows:

1. A design-build single contract.

2. A single contract for building all components (separate design by the owner or others).

3. Separate contracts for various areas of work expertise required (i.e. Equipment supply, clearing, pipe work, construction, mechanical, electrical).

There are trade offs to be made in each type of contract arrangement. Comprehensive design-build contracts may be the simplest to manage, with clear responsibilities borne by the main contractor to complete all the work and undertake responsibility for coordinating subtrades and absorbing any resultant delays. However, a premium may be paid for this service. The contractor effectively manages the project, may take a mark-up on the work of subtrades and may charge a premium on the increased responsibility and risk he is taking.

By going to single contracts for various phases of the work you must absorb the responsibility for coordinating contracts and ensuring that the actions of one contractor do not interfere with those of another. In return for taking this responsibility, bids may be lower because work packages in specific trade areas can be defined. In addition keeping contracts small allows a wider range of contractors to bid. You can further help your cause by arranging clearing in advance of the main contracts.

Most small hydro projects involve rugged terrain, and if the clearing is done ahead of pre-tender inspection visits, the contractors will be able to prepare their bids with less risk of unforeseen extras.

Contractor's Responsibility

The Contractor's responsibility should be clearly spelled out in the Contract Documents. However, note that the following points should be covered as the contractor's responsibility:

(a) materials, delivery, handling, storage (unless otherwise specified);

(b) men and equipment, accommodation, fuel, repairs;

(c) performance of the work within the specified time;

(d) payments to suppliers and subtrades;

(e) adherence to regulations governing construction;

(f) evidence of insurance, bonding, and payment to subtrades.

Owner's Responsibility

As the Owner your responsibility should also be clearly defined in the Contract Documents. The following points should be covered.

1. The Owner is responsible for having permits in place (land occupation and water rights) to allow the work to proceed.

2. The Owner shall have the site ready for construction, as defined in the Contract Documents. If the site requires clearing, then who does the clearing should be specified.

3. The Owner shall pay the Contractor monthly progress payments based on the fraction of work completed. The Contractor shall be entitled to interest at the prevailing rate on late payments.

4. The Owner shall ensure that any goods or services he has contracted to provide are indeed provided; otherwise claims from the Contractor can be expected.

5. The Owner shall provide the project plans and specifications which the Contractor shall follow. Any errors in the plans shall be rectified at the Owner's expense. However, the Owner may have recourse against the designer if any error of negligence is discovered.

Contract Security

Contract security can take many forms. It is essentially a form of guarantee to you, as the Owner, and ensures that the work is carried out by guarding against the insolvency or incompetence of the Contractor. There are two types of security.

1. The Bid Bond, usually in the amount of 10 percent of the tender price, ensures that the low bidder will actually execute a contract. If the bidder withdraws his tender for any reason, the bid bond helps you to pay for the higher cost of the second bidder.

2. The Performance Bond and its variations usually in the amount of 50 percent of the Contract Price, ensures that once a contract is executed, the work will be completed for the Contract Price. In order to qualify for the bonding, the Contractor must have proven himself on jobs of difficulty equivalent to the present work. If the work is not completed, the bonding company is required to complete the work up to the limit of the bond. The Performance Bond is often accompanied by a Labour and Materials payment bond, generally in the amount of 50 percent of the Contract Price. This guarantees the work force, subtrades and suppliers will be paid up to the stated limit in the event of insolvency of the Contractor.

An alternative to the bonds, which is more suitable to some smaller Contractors is the Letter of Credit. This document, issued by a bank, is in an amount of about 50 percent of the contract value, more or less to suit circumstances. It guarantees payment by causing the bank to hold security on the Contractor. If there is a requirement to pay suppliers or complete unfinished work, you can claim on the Letter of Credit (supporting documentation may be required). The bank will then claim on the Contractor.

In addition to the above noted forms of security, all Contractors shall be obligated to carry insurance on vehicles, equipment, materials, personnel and partially completed works. You as the Owner shall be named on the policy as a co-insured, and liability protection shall be provided against personal injury and damage to other properties. You should also consider taking out your own policy to cover any areas not the responsibility of the Contractor.

If you choose, you may avoid any of the above forms of security, perhaps at some savings. However, you will then be entirely at risk in the project and any incidents could result in high unpredictable costs.

Penalty or Bonus Clauses

In order to enforce the time of completion in the contract, there is usually a penalty clause, which represents your extra costs due to late completion. If there is a penalty clause, there may also need to be a bonus clause for early completion. They do not need to be for the same daily value.

7.3.3 Construction and Contract Management

Coordinating Work

When a project is underway there must be an individual responsible for administrating contracts and coordinating the work of the Contractors. In a small project, you will usually do this job, while in larger projects a manager may be hired. In either case the duties will be the same and they are detailed in the following sections.

Materials Handling

Most of the materials used in a project are imported to the site, and as such they must be purchased, shipped, stored and moved into place. In most cases this task is delegated to the Contractor responsible for the relevant portions of the work. However the manager of the project should also be aware of special handling requirements of the materials, so he can keep alert for practices which could cause future problems. This is especially important if you have taken responsibility for supply of some materials. It is important to inspect materials at each stage of handling to note any shipping damage, then store the materials properly before handing possession in good condition to the Contractor.

Inspection and Progress Monitoring

Once on-site work is underway, the only means you have to ensure that quality is maintained is through inspection. This is especially important where sections of the work are covered after completion, such as concrete reinforcing, buried pipe, and building frames. Inspection is also a means to monitor work progress. This will ensure that the status of the schedule is maintained and that progress payments are justified.

Progress Payments

The Contractor is entitled to progress payments upon completion of work milestones or on a monthly basis. The Contractor may also be entitled to payments for materials delivered to the site. The manager will evaluate the materials and work progress to date, then deduct the value of works already paid for. A holdback, which by provincial legislation may be in the amount of 10 percent of the value of work completed, should be applied to cover the cost of claims against the Contractor by his subtrades and suppliers. If the holdback value retained is insufficient, the Letter of Credit or Labour and Material Bond would then be used.

Extra Work Orders and Claims

In most contracts, unforeseen situations arise which will cause the Contractor delay and/or expense. Where these occur, the amount of work should be defined, prior to its execution and written authorization provided. You have the option of paying for the work on a force account basis (using stated values for the labour and materials at cost plus mark-up, detailed in the Contract Documents) or of requesting the Contractor to provide a fixed cost for completing the defined extra work. The agreed value of the work is then added to the contract. Other claims by the Contractor for conditions which were not as defined in the Contract Documents should be resolved soon after they occur,when the facts are still fresh. Written communication and acknowledgement must occur.

As-Built Drawings

At the conclusion of the project, the Contract Drawings should be modified into As-Built Drawings to reflect any changes made. The drawings will be required as part of the water licence and will prove of benefit in future to show what is there, especially for the areas of work which are covered. They may also be required for insurance purposes.

7.3.4 Completion of the Project

Contract Completion

At the conclusion of the project construction, the Contractor will apply for a Certificate of Substantial Completion, which will start the 40-day clock ticking towards the release of the holdback. Prior to issuing this certificate, you must evaluate the work, prepare a deficiency list if necessary and re-read the contract to ensure that all clauses have been complied with. While the holdback period is underway, you should check that all suppliers have been paid and obtain a Statutory Declaration of payment from the Contractor.

Such thorough actions are more necessary where small contracts are issued, to ensure that subsequent Contractors take over the work in the expected condition.

Liens and Holdbacks

As described above, the purpose of holdbacks and labour and material bonds is to settle claims against the Contractor. If these claims are not settled, the parties affected have rights to put a lien on the property. While this in itself may not pose a direct problem, you could be prevented from selling the property or obtaining a mortgage without clearing the lien.

Similarly if you fail to make a payment due or settle a dispute, the Contractor could place a lien on the property. Improper liens, should they occur, can be dismissed through legal action.

Commissioning, Warranties and Maintenance Manual

The final stage of constructing the small hydro project is the commissioning. This is usually performed by a representative of the turbine manufacturer who will install, align and test the equipment. In order to successfully accomplish this, all aspects of the water delivery system to the turbine must be complete, and the power delivery system from the generator to the load center must also be complete. With this infrastructure complete, responsibility for the commissioning clearly rests with the turbine manufacturer's representative.

At the point of commissioning, the warranties on the project will begin, usually lasting for one year. Your responsibilities and those of the manufacturer must be clearly defined in advance, covering the routine and emergency maintenance. Warranties on other portions of the work will usually begin at their respective dates of substantial completion.

It is important from the standpoint of future maintenance to have an Operation and Maintenance Manual for the project, and to follow it. Most of the input will come from the turbine/generator supplier, who should provide a manual as part of the equipment package. Other operational considerations should be provided by the plant designer. Particular attention must be paid to intake clearing and freeze protection. Even though you may understand the duties required, they should be written down for the benefit of any future owners or operators of the plant. A detailed log book of maintenance procedures, weather conditions and meter readings should be kept.

Final Inspections

The last step in the process is the final inspection. This will certify that all of the Contracts are totally complete and that all deficiencies have been rectified. It is also usually a requirement that the entire electrical installation be inspected by the provincial electrical inspector. The inspector will check that all parts of the electrical system meet code requirements, and any approvals of electrical contract work should be made subject to the provincial inspector's approval. It is worthwhile making a final inspection of all project components just prior to the expiration of the one year warranty.

7.4 PRACTICAL NOTES ON BUILDING A SMALL HYDRO POWER PLANT

7.4.1 General

In this manual you have been made aware of virtually every facet of the small hydro development process. In this section some insight is provided into those aspects of the process which can only be learned through experience, or the use of experienced design personnel. While it may be difficult to describe every possible situation, it is hoped that the discussion will prompt you to do further research on your own to provide a solution which is correct for the situation, or, alternatively, to seek advice.

7.4.2 Design

The objective of a good design is to provide the lowest cost project consistent with considerations of safety, the expected life of the project and the expected performance of the project. However, in projects of the size covered by this manual, there are usually strict limits on how much design effort can be expended relative to the cost of the project.

After the design process, consideration must be made of other factors which affect the project. You may be able to provide a measure of the "site factor" which increases costs due to rough terrain and remote locations. Some construction savings may be possible if you are prepared to undertake higher maintenance costs. While the actual details of design have been worked out based on earlier chapters, a few additional conceptual ideas are be presented below:

1. The design should take advantage of locally available materials and skills.
2. The project should be laid out for ease of servicing and flexibility if future changes are contemplated.
3. Excavations on steep slopes or on unstable soils should be kept to a minimum.
4. The lightest weight pipe available should be considered for low pressure sections and the use of steel avoided, unless maximum advantage can be taken of its high strength for high pressures or for long spans. Do not choose lightweight pipe that will be easily damaged in handling, or subject to vacuum collapse.
5. Where conditions permit, the pipes should be buried.

7.4.3 Construction

Many of the procedures in managing the construction of a small hydro project have been discussed in Section 7.3, but it is worth mentioning a few attitudes towards construction which may be especially relevant if you choose to do much of your own work. In a

Contractor-built project, cost saving procedures and quality control monitoring are the Contractor's responsibility, so these attitudes are less critical to you.

The most important aspect of owner-built construction is the effective utilization of labour and materials. Start with a plan, and provide options to allow the work emphasis to shift if required. Make sure materials are readily available and that equipment is sized for the job. Above all, schedule the work to take advantage of weather conditions. This usually means avoiding winter work, thus improving the speed and quality of the construction. As the owner of a self-constructed project you should also be more aware of erosion and corrosion problems. Erosion must be watched so that construction activities do not lead to undermining existing facilities: usually this involves controlling runoff water. Corrosion becomes an important consideration when steel and/or dissimilar metals in contact are exposed to the atmosphere. Proper protection must be applied and dissimilar metals should be avoided or checked with a galvanic series chart. In addition, damage to protective finishes must be touched up.

The final note on construction concerns safety. Although the Worker's Compensation Board provides protection and regulates safety practices, there is no protection available unless a premium is paid. Alternative protection could be arranged with private insurers, but this would not absolve you or the contractor of the legal consequences of poor safety practices.

7.4.4 Operation

After commissioning, you will operate the power project. Much has been written about the low maintenance aspects of small hydro power, but this does not mean no maintenance. Following the instructions of the Operation and Maintenance manual will help to ensure that the project last for its expected life. There are only a few areas which will be noted here as requiring extra precautions, as they can lead to catastrophic failures.

Overspeed results when power demand is reduced without a corresponding decrease in the water flow. There should preferably be a backup shutdown device as well as an alarm.

Water hammer results from the sudden change of velocity in the penstock through the opening or closing of the valve. In addition to a protection system on adequate penstock design, you must exercise caution whenever a valve is manually closed.

Freezing can occur on any location in British Columbia, and can be a problem in columns of standing water, exposed valves or small piping. It will not be a serious problem in the main penstock (except under the very coldest conditions) unless the plant shuts down. If this occurs, efforts must be made to either restart the plant or drain the penstock as quickly as possible. In order to facilitate drainage, low spots in the penstock should be avoided or provided with drain valves.

7.5 PRACTICAL NOTES ON DEALING WITH A CONTRACTOR

7.5.1 Objectives of the Contractor and the Owner

Although you as the owner and the contractor have been brought together for the common purpose of developing a small hydro project, this is the only thing you have in common. Your underlying objectives in achieving the common goal are quite different; for you are attempting to secure the highest quality job at the lowest overall cost, while the Contractor is attempting to maximize his profit and enhance his reputation. These differing objectives are incompatible and are the main reasons for small disputes becoming big disputes.

7.5.2 Design and Contract Details

The main tool for avoiding disputes is a well written Contract Document and clear drawings. These must be based on enough design information to know exactly what is going to be built and enough field investigation to recognise where potential extra works exist. The areas of uncertainty should be well covered by addition/deletion clauses or unit prices.

7.5.3 Progress Monitoring

The Contractor must be regularly inspected to monitor quality and progress, and to make you aware of potential cost changes. While these have been discussed in Section 7.3.3, Extra Work Orders and Claims, it is worth mentioning the importance for the job inspector to recognise when potential cost overruns could occur. Special note should be taken when items have a high upper bound of quantity, such as earthwork or concrete, because these items could severely affect the project budget. The job inspector's duties should include progress monitoring, quantity and cost projections and liaison between you and the contractor. Numerous photographs and notes on the contractor's work progress may be helpful in settling disputes.

7.5.4 Reasons for Disputes and How to Settle Them

Despite taking the precautions previously outlined, from time to time disputes will occur. In most cases a dispute between you and the Contractor will be the result of a misunderstanding caused by differing interpretations of the contract documents or drawings. The contractor will usually expect that he should do less work for the same money, or more work for more money; while you will take the opposite view. Sometimes the dispute results from an inherent flaw in the Contract Documents, while at other times the dispute arises from a condition or event unforeseen at the time of signing the contract. In many cases, the dispute may result from delay cost, either through your failure to deliver a promised service as per

Section 7.3.2, Owners Responsibility, or through the actions of another Contractor being late to finish a critical section of work.

Once it is established that there is a dispute you must take steps to minimize your financial risk. The first step is to recognise, through the site inspection, when a problem begins. At this point, the contractor must be advised in writing of the proper action to take, and careful account must be made of the labour and materials expended. The contractor must also be made aware of contract clauses, usually found in the General Conditions, which obligate the Contractor to inform you wherever he encounters extra work. Such measures will result in you maintaining control by turning the dispute into an extra work order, with limits on the cost.

There may still be disputes which arise after the contract is completed. Whether they are valid claims or not, you must acknowledge them and depend on your detailed records of construction activities to verify or challenge the claim. The difficultly with claims is that there is usually some degree of validity to them and the contractor will usually fight hard to prove his point. Your task is to minimize your total cost, both in fighting the claim and in paying the claim. Some ranges of outcome are discussed below:

1. The claim may be frivolous, or in fact covered by an obscure clause in the contract. In this case you would be within your rights to refuse the claim, stating the reasons why. If the Contractor recognises that his claim would not stand in court, it would be withdrawn. Alternatively, you could raise the matter of offsetting counterclaims in an effort to diminish the claim value.

2. The claim may have some validity, but may be of modest value. In this case you would be wise to document your interpretation of the claim, again depending on good site records, and offer a negotiated settlement. It could be less expensive than either Item 3 or Item 4 below.

3. A more substantial claim may be sent to arbitration. This is a neutral body, who upon the agreement of the disputing parties will submit a recommendation for settlement. The cost of the arbitration process alone can be $6,000 to $8,000 for each party.

4. The last resort for both parties is the court system. This should be reserved for only cases of high value and deeply entrenched views: in other words a total impasse. The expenses of legal fees, court costs and time (civil court bookings take at least a year to reserve) plus the risk that either party could spend a great deal and end up with nothing, means that the courts should be used cautiously.

7.6 CONCLUSIONS

It is difficult in a chapter of this size to provide examples of every situation you may face, but it is hoped that by being better informed you will appreciate your responsibilities. If you provide adequate documentation for all phases of the project, you will be in a much stronger position to deal with approving agencies, financiers and contractors.

8. LOW HEAD CONSIDERATIONS

8.1 Introduction

Most of the world's hydro power developments have been low head, under 10m (33 feet) and concerned with the direct mechanical use of the power for irrigation and milling purposes, rather than for generating electricity.

Some of the earliest technologies, the paddle wheel and the tidal mill have flourished, withered in North America, and are now showing signs of revitalization. The use of new and different materials for machinery and construction allow fresh approaches to development. Applications from other fields, such as pumps and ships' thrusters, are being found suitable for hydro power. The economics of standardization of units and large production runs have been applied, together with packaging of units, helping to defray the costs of on-site construction.

There are new methods being developed and some older ones being re-consideration, which could prove advantageous to future low head development.

Theoretically any head can be utilized through one device or another to produce power. Whether incorporating the device is economically justifiable will continue to remain location and time specific. Potential developers of low head hydro should remain aware of their options rather than accept the position that there is only one way to go.

Opportunities presently exist in B.C. to exploit the potential of the many hundreds of low dams impounding water around the Province for a variety of purposes. Securing a water source is often the over-riding cost factor in low head developments. Often quite simple changes or additions to existing structures can make an application of low head hydropower viable, to the mutual benefit of both the original owner of the facility and the developer.

8.2 Water Wheels

Hydro-power was being exploited long before any theoretical basis for the design of the apparatus was available. In China and in the Middle East, water wheels were being operated thousands of years ago, using the energy derived from relatively slow moving rivers to raise water for irrigation. Two basically different types of wheels evolved based on the availability of local materials.

Fig.8.1 shows a type of paddle wheel where the paddles are hollow bamboo containers, mounted inclined to the axis of the wheel such that when the containers dip below the stream surface, they fill with water, and as they are raised out of the stream, they trip and discharge into a trough at some higher level. Motive power comes from the stream pushing the below-surface containers along, and around. The size of such wheels and their their output was probably dictated by the availability of sufficient large and matched bamboo containers. Such considerations need not limit the size of a modern application of this type.

In Fig. 8.2 a second type of wheel is shown in which containers are mounted around the periphery of a relatively narrow wheel. Again the force of the stream on the container provides motive power. Where the stream power is insufficient to lift full containers with the axis wheel mounted horizontally, these wheels are often mounted with the axis inclined such that more of the containers and even some of the spokes will be acted upon by the stream whilst the height of the required lift will be reduced.

Both of these types of wheels would have very low overall efficiencies, but both did and still continue to do useful work.

The third type of waterwheel is the open paddle wheel. Fig.8.3, where the vanes of the wheel are flat boards, again pushed by the water, thus turning the wheel. This wheel could also be used to raise water for irrigation or domestic consumption by either the addition of containers directly to the wheel, or by connecting a second wheel supporting containers, directly to the axle of the first wheel.

Through the use of gears, or pulleys, these water driven wheels could be made to do other useful work. A simple mechanism converting the circular motion to a reciprocating motion allowed the power to be used for driving wood saws.

With the advent of steam powered reciprocating engines the power could in effect be reversed, with the engine driving the paddle wheel, and large shallow-draught river craft were thus enable to navigate upstream. Many examples of such craft were to be seen at the turn of the century on B.C. rivers and lakes. It has recently been realized that mooring such a craft in the current would allow the paddle wheel, through suitable gearing, to drive electric generators, and a California company is developing such a craft with potential generating capabilities of up to several thousand kilowatts.

In all of the above described hydro-power applications, the wheel was brought to the water. This situation had certain disadvantages which included:

(a) naturally fluctuating stream levels, causing the situation whereby a wheel which was tuned to operate relatively well at one level of water might not operate under other levels;

(b) obstructing the natural channel;

(c) requiring the wheels and their support to be either constructed at some other location, then transported and erected where required, or constructed on site having to take account of the stream flow during construction.

(d) having to contend with any materials floating on or in the stream, or any bed-load;

(e) having to bring the work to the source of power;

(f) preventing the wheel from turning faster than the stream flows.

Bringing the water to the wheel solved many of these potential problems, and motivated a number of different approaches to both the design and use of the water wheel.

The undershot water wheel, Fig.8.4, was a simple paddle wheel constrained in a passage of water. The wheel can operate under a head as low as 0.3m (1 foot). There is an immediate gain in efficiency over the 'open wheel' as eddy losses around the sides and bottom of the vanes are reduced. Because of the water passage constraint, the water level upstream of the wheel will rise thereby increasing the head on the wheel.

To further reduce eddy losses, the sides of the wheel can be enclosed, Fig. 8.5

A further adaption of the undershot wheel in which the blades were curved to provide more efficient water interaction, the Poncelet wheel, Fig. 8.6, makes use of the velocity of the water which has been held back and forced through a narrow opening. The rather complicated breastwork, set to close tolerances; was accomplished by using concrete, and metal replaced wood for the blades.

If suitable headrace (upstream conduit) can be constructed, the rather gradual drop over a length of the river can be concentrated at the waterwheel, with further increase in efficiency. The Breast Wheel. Fig. 8.7, is arranged for water to enter below the top of the wheel, and operates best at heads of less than 3m (10 feet).

The breastwork, which helps constrain the water in the buckets, may be rather complicated to construct, and the wheel itself becomes more complicated. Efficiencies however can approach 65 percent with water entering above the axis of the wheel.

If over 3m (10 feet) of head could be made available the Overshot wheel, Fig.8.8, a rather simpler construction could be used with the weight of the water in the rim buckets causing the wheel to turn.

8.3 Modern Turbines Types

With power proportional to the product of head and flow, low head plants require quite large flows to be handled in order to produce reasonable power. (For example, with a 2m drop available, $10m^3/s$ of flow must be passed through a turbine to produce 140kW).

This means large intakes leading to large water passages and large turbines contained in large structures. All of these point to large costs. Developers of low head, small hydro machinery have been forced, in trying to remain economically viable, to reducing the size of their machines and standardizing on product lines of fewer machines. This still leaves a number of type of machines available, and even within types, configurations can be changed in order to realize even further economies. Some manufacturers have taken to producing whole packages, from intakes to draft tubes in order to take out as much of the uncertainty as possible. This reduces the costs for contingencies.

An introduction to turbine types was given in Chapter 4, some further notes, particularly relevant to low head types are given here. Fig 8.9 shows some of these types of turbines in typical settings.

Francis Turbine, vertical axis, heads over 5m (16 feet)

These turbines run slowly and probably require either gearing, belting, or some other type of speed increaser to drive a reasonable sized generator. They are big machines requiring large housings, and a right angled draft tube. In general, vertical units are more cost competitive than horizontal units when the throat diameter of the turbines is over 1.2m (4 feet).

Francis Turbine, horizontal axis, heads above 8m (26 feet)

Driving a horizontal axis generator smaller in size with reduced thrust bearing requirements, these turbines require a longer shallower housing than vertically mounted units.

Propeller (Kaplan) Turbine

Power output is controlled by wicket gates and/or positioning of the runner blades.

- Vertical axis, fixed blades

  Having a sharply peaked efficiency curve, this type operates efficiently only within a narrow band of flow and head.

- Vertical axis, adjustable blades

  This type has a broad, flat efficiency curve over a wide range in flow and head. It is less likely to cavitate when operating off optimum rated conditions than flexible blade types. Increased maintenance is required by the adjustable blade models.

NOTE: both Francis and Kaplan turbines can operate in either open or closed flumes.

Tubular Turbines, heads above 2m (6.5 feet)

Horizontal or slant-mounted units with propeller runners, either fixed or viable pitched, with or without wicket gate assemblies. The generator is located outside the waterway passage, resulting in increased floor space but reduced height requirements.

Bulb Turbines

Horizontally mounted units with wicket gates and fixed adjustable propeller runners directly connected to a generator located in the water passageway, in a watertight enclosure. The straight water passages minimize head losses. The powerhouse can be low and relatively compact.

Rim Turbines, heads ranging from 2m (6.5 feet) to 9M (30.0 feet)

The generator rotor is mounted on the periphery of the turbine runner blades and makes for compact housing for this type of turbine.

Crossflow Turbines, head above 2m (6.5 feet)

Essentially an impulse type development of the undershot wheel. Low specific speeds result in large dimensions, and the requirement for speed increasers to increase generator speeds. The relatively flat efficiency curve allows operation over large ranges of flow and head. Unit generally run cavitation free but are subject to scour wear if there is silt in the water. With a conical draft tube the unit can be mounted up to 10m (33 feet) above the tailrace, without losing efficiency.

8.4 Package Units

Several companies have standardized their low head hydro unit production in order to offer complete, tested installations available either off-the-shelf, or more quickly than has been usual with site-specific designed units. In most cases the units have been designed to cater to specific development applications. To modify these units for other applications might negate some or all of the savings they originally offer. Some examples of different types of units are given below.

Allis-Chalmers TUBE Turbine Units (Fig.8.10) are designed to be utilized in existing waterways and power houses with a minimum of new civil construction. There are ten sizes available to operate under heads from 2 to 15m (6 to 49 feet) and ranging in output from 60 to 6,000 kilowatts. These are well suited to retro-fitting low-head power plants. They can be arranged with either vertical or horizontal shafts. The horizontal shaft arrangement generally permits installing more capacity within a given space as compared to the vertical arrangement. The vertical arrangement can reduce the length of the powerhouse and facilities locating the generator well above flood level elevations.

Tube turbines are propeller-type units which provide the highest possible operating speed and the maximum capacity for a given size. If more than one unit is installed, unit spacing is only two-thirds of a conventional vertical turbine for the same head and turbine control.

Galt Energy System's Inverted Siphon System

Incorporates a standardized 'L' turbine available in twelve sizes (2 to 3,000 kilowatts) in operating ranges between 2 and 12m (6 to 40 feet), placed on top of a siphon loop across a dam.

The systems offers the following advantages:

- the high turbine position gives flood protection and allows for an inexpensive, effective draft tube;
- no valves or stop-logs are required for flow control;
- civil works are simple and, in most cases, form a small part of project costs;
- monitoring and maintenance are easily accomplished;
- no heavy objects are likely to pass up through the unit;
- the requirements of a trash rack is minimal, and might in certain cases be eliminated;
- shallow forebays can be used without danger of drawing air into the siphon;
- by controlling the amount of air admitted into the siphon loop, any no-load speed and its related flow can be maintained.

The "L" turbine has the unique feature that the water is directed to the blades through a single rectangular passage that forces the correct rotation and direction to the water flow without the use of guide vanes. The rectangular intake discourages the tendency of the incoming water stream to rotate and form eddies that draw air into the system.

Flygt Submersible Turbine-Generators

These are adaptations of a line of submersible pumps. The turbine-generators are available in six basic sizes, with capacities from 30 to 500 kilowatts, from heads of between 2.5m (8 feet) to 15m (49 feet).

The fully encased units are delivered in one piece and can be lowered into the powerplant as soon as the structure is completed. Maintenance requires the lifting out of the whole unit.

8.5 Variable Heads

All hydro plants must cope with variations in head, but these normal variations assume greater importance in low head plants.

Intakes operating year round must be located below the minimum expected water level, which might be far below the maximum level. Low head intakes are relatively large, and the gates and valves involved in water control are also large and expensive. Additional lengths of gate guides and other operating equipment add further cost. The larger intakes must usually be designed to be completely closed to allow for cleaning when the trash racks clog, leading to heavier sections. Uplift pressures causing the whole intake to float out under closure conditionings requires careful considerations on these relatively large structures; either extra concrete must be provided, or any rocks or other materials used to provide additional weight to the structure must be placed where there is no danger of being inadvertently removed, or swept away by swirling and eddying water.

When the turbine axis is fixed relative to the ground an increase in upstream head may cause too much water to enter the turbine, leading to overspeed and straining of the turbine blades. Either less water must be admitted or the blades feathered, either solution requiring more machinery, and closer attention to the operation of the plant. Both add expense.

In the absence of a dam, upstream water levels are due to natural river level fluctuations. The elevations of past floods can often be deduced from observing the shape of the river bank, the absence of vegetations below certain levels, or the rubbed bark of the trees adjacent to the river. There ar methods whereby hydraulic engineers can deduce water surface elevations for various flow rates, as well as giving advice on what reasonable levels to design for. Similar considerations apply at the tailrace of the development, which must have sufficient water at all times, yet be guarded from the effects of flooding.

When a dam is present, original water levels will be backed up and historial flow levels can only be useful to help arrive at the historical rates of flow. Upstream water level fluctuations will depend upon the rate of water flowing into the reservoir. The presence of a dam usually means less fluctuations of upstream water surface elevations, but only if sufficient capacity to pass floods is provided.

The effect of upstream head variations on power output depends on the ability of the turbine and generator to usefully accommodate the changes. If the plant has been optimized to produce sufficient power at the lowest head and there is no need for more power, then the turbine requires some throttling device to ensure that greater flows will not harm it. If, however, use can be made of the extra power available, both the turbine and generator must be sized to be capable of handling that situation.

Tailwater fluctuations also may change the power output, depending upon the type and elevation setting of the turbine. Turbine centrelines can be set above or below the tailwater level, the actual location depending upon design parameters which the turbine manufacturer requires to be met to ensure the turbine gives efficienct and trouble-free operation. The elevation, of the turbine may be effected by the actual elevation at which the development is located. It would be possible in B.C. to have the same turbine operating at sea level as at say 2000m, each location requiring a different setting.

Turbines need to be designed to avoid the onset ofcavitation, which is a phenomenon whereby local pressure at the turbine blades falls below the pressure at which air bubbles can form in the water. Subsequent collapse of these bubbles at the blade surface can cause pitting of the blades leading to progressive loss of efficiency, and rough operation of the turbine. Where cavitation occurs, maintenance costs are greatly increased and the turbine can often become completely useless in a short period of time. The developer must inform the turbine manufacturer of both the true elevation of the development and the fluctuations in head and tailwater under which the turbine must operate. Failure to do so, or to attempt to operate the turbine outside of the specific limits could void the manufacturer's performance guarantees.

The need to set the turbine differently with respect to the actual elevation of the project should be borne in mind when using second-hand machinery not originally intended for the new location. If possible the original manufacturer of the turbine should be approached for advice on the required setting; old drawings of the original set-up may not be valid.

In comparison with the higher head plant of, say, 50m (164 feet), where a 1m (3.3 feet) head loss would result in only a 2 percent power loss, a 5m (16.4 feet) head plant may lose well in excess of 20 percent of its power for 1m (3.3 feet) head loss due to a combination of reduced head and reduced turbine efficiency.

Installation Requirements

Low head developments can be located either on the coast, on natural stretches of river, utilizing lakes or falls, existing ponds or canals, across dams or spillways or drop-structures, on existing pipelines, tunnels, troughs or other water conveyance structures. The water used can be salt, fresh, treated or contaminated.

Each situation must be examined for its merits and drawbacks before the most appropriate method is chosen.

Some considerations are common to almost all hydro-power developments, and bear repeating.

a) Plan as much as possible for construction in the river to coincide with low expected flows; handling less water will be less costly.

b) Prefabricate as much of the work as possible off site; on site work is usually more expensive.

c) Pre-plan as much as possible before committing personnel, materials and equipment to a site.

d) Order things well in advance.

Other considerations are more specific to the various types of low-head development, some or all of which may be relevant in any particular case.

Control gates, valves

The larger types require a lot of effort to operate. If the operation is manual, it will be slow because of the high gearing required. The friction on simple sliding surfaces might be too much to overcome if movement is required under extraordinary conditions. Long gate stems must be shielded from debris and well supported or they may bend. Operation should be checked regularly.

Canals

Structures located adjacent to bodies of water where ground water levels tend to be high, or themselves contributing to high ground water levels through leakage, should be carefully designed to prevent uplift or flotation when empty. Either the materials surrounding the structure must be well drained to allow water to leave the vicinity, or sufficient load must be attached to the structure, either additional mass or anchors, to hold it down.

Large Diameter pipes

If buried, these pipes must also be prevented from floating out when empty. If above ground, the pipes must be adequately supported to prevent collapse during all phases of operation, and during construction. Low pressure pipelines gain little strength from internal pressure helping to round them out. The relatively thin pipes have a tendency to widen and flatten, especially when partly full.

Handling the pipes into position might provide the governing criteria for ordering pipe thicknesses. Steel pipe should have a thickness of at least 1/400 of the diameter, plus 1/20 inch, unless special precautions to provide handling rigidity are provided. Concrete, PVC and polyethylene pipes will probably be already more than adequately thick for handling, at a cost which cannot be avoided. Pipes constructed from corrugated, galvanised steel must be particularly well supported so as not to either distort or float. Wooden, banded pipes will have been specified with the type of support and conditions of operation particularly in mind.

Air vents/vacuum breakers

When provided these must be well maintained to avoid penstock collapse. They require adequate room for air to move through. Snow should be kept clear and blockage by plants and leaves guarded against.

Utilizing existing structures

Once permission to utilize an existing (dam, canal, pipeline, or whatever) has been obtained, as much information as possible about that structure should be gathered in order to evaluate it's suitability. No structure should be assumed sound just because it appears to be so. An apparently sound concrete dam might have suffered internally from chemical disintegration of its aggregates, or even if still whole, might be on the point of instability due to changes in uplift pressures. Frost action may have penetrated deep into reinforced concrete canal or training walls, allowing corrosion and subsequently loss of much of the strength of the section. Blocked drainage paths or scoured backfill might leave a section of the canal just on the point of floating out of the ground and a rapid emptying of the canal or nearby blasting could just trigger the failure.

Old steel penstock pipes might literally be on the point of corroding away or be over-stressed due to loss of support, failure of expansion joints or change in operating circumstances outside of the original design.

The operating frequencies of the proposed development could cause resonance in existing pipelines, resulting in overstress conditions. Operating the control devices too rapidly could cause partial vacuum in low head pipes not designed to accept such conditions, or cause operations outside the scope of the existing safety devices.

In certain circumstances extending the use of an existing structure will require that structure to be upgraded to a new standard which might make the project uneconomic. Spillways and electrical works often fall into this category.

There are, however, many possible advantages to being able to use existing facilities.

Dams

Once a dam is built on a natural watercourse the flow downstream of the dam is at least partially regulated. This is to say, the rates of flow which once were natural are changed. Peaks and valleys of stream flow are attenuated by a dam and outflows below the dam are less erratic. Reservoir elevations fluctuate with the rate of inflow and outflow; the larger the surface area of the reservoir, the smaller the fluctuations. Hydro plants drawing from the reservoirs will probably require less costly water intakes than those required to accommodate the larger natural fluctuations. Additionally, the operating head on the plant will have less variation, probably allowing the turbine to operate in a more efficient range for a longer period of time.

Dams are usually costly to install and construction of them must be started well ahead of the initial production of power. It might also take some time for the reservoir to fill before the useful water level is reached. An unusually dry season could put power production back a whole year, delaying returns on the initial investment.

Existing dams change the previously existing environment creating new and presumably acceptable situations. These will usually not change substantially with the inclusion of a hydro facility. Even beaver dams can be successfully utilized, but too much reliance should not be placed on their permanency.

Floating debris is often easier to handle on a reservoir surface than on a natural watercourse and much of the silt and gravel travelling along the stream bed will have settled on the reservoir floor before it need effect any power intake.

Existing reservoirs have often attracted a recreational community which proved a ready market for hydro-power produced electricity.

Spillways

Almost always associated with dams, but not necessarily an integral part of the dam, the spillway is probably the most likely place to incorporate a powerplant. Spillways are usually located on firm foundations, and might incorporate structures or mechanical control devices which could readily be made use of. Spillways are obvious sources of wasting potential energy, some operate year-round, whilst others are subjected to well defined and controlled operation. These operational requirements must obviously be taken into account when planning a hydro installation.

Spillway structures, will probably have access already provided to them, representing another savings to the potential developer.

Canals

Irrigation canals are often not required to operate for their intended purpose for more than a short period of the year, which leaves much of the year they could be dedicated to supplying water to a hydro-development. Also, a normally designed canal may have more carrying capacity than was originally required because the designers are typically conservative in estimating friction losses. Thus even during periods of use for irrigation, excess capacity might be available in the canal.

Well designed canals have regulated water surfaces. This produces closely defined operating heads on the hydro plant, and allows a turbine with a small head range to be used.

The hydraulic characteristics of the canal must be obtained so that the effect of incorporating a hydro plant can be studied. Sudden load acceptance or rejection will cause surges along the canal which must be acceptable to its operation.

Pipelines

Existing pipelines should only be incorporated into hydro-electric developments when it can be proved that the operation of the plant will not load the pipeline beyond safe limits.

Large diameter pipes are costly and would be designed only for specific operating conditions. Of special concern are any conditions which might induce a vacuum anywhere in the pipe. It is inadvisable to install a device to alleviate the condition, rather than have the pipe strong enough to accept the situation. Such devices have a habit of not working after long periods of inactivity, having been poorly, if at all, maintained. The collapse and subsequent washout of such an over-stressed pipe can be a costly event to remedy. Large diameter pipelines require specialized design.

Innovative Applications

Innovation applies equally to equipment, materials, methods of planning and construction as to the various situations for development to which they may be applied. The use of inverted siphon packages could be extended by having both the intake and the outfall supported on floating barges. Fluctuating water surfaces would no longer be the problem they have been to date; a more constant head difference would allow for more efficient overall operation.

The undershot waterwheel is being redesigned in modern materials and with the applications of sophisticated methods of hydraulic design increasing its efficiency. There is an almost unlimited market for such a simple device in countries with extensive irrigation requirements.

Low dams consisting of air or water-inflated membranes originally developed for shorter term construction applications, are being considered for longer term developments, possibly in conjunction with the floating siphon powerplant.

Barges, either supporting or containing low head machinery can be constructed where labour, materials and equipment are more readily available. These could then towed into position and moored where required.

Where pressure reducing valve have been required in municipal and industrial water supplies, the excess pressure may be used to generate power.

Sewage systems and other foul water systems, previously requiring energy dissipating facilities, are being used to drive low-head hydro-power generators.

Canal locks, irrigation canal drop structures, weirs and other dams can often be economically retrofitted with power producing facilities with the minimum of disruption to their existing operations.

Developments in wave generated power production, presently applicable to very small power production for remote navigation buoys, will be extended in size and application. A recent demonstration funnelled waves into a converging channel, forcing them up to replenish a pond from which the water drains through a low-head generating device.

Potential hydro-power developers need not believe only high-head developments are viable. There are probably more opportunities for low-head development even in a province with such spectacular topography as ours.

Tidal Power

A number of potential tidal power sites have been identified along the B.C. Coast, where the tide can range above 5m (16 feet). A hydro-generating unit utilizes the head difference between water stored during high tide and the height of the receding tide.

The unit needs to be capable of efficient operation under a large range of head. It also helps if the unit is reversible or can be arrange to operate with incoming or outgoing tides in order to increase the overall energy output per tide.

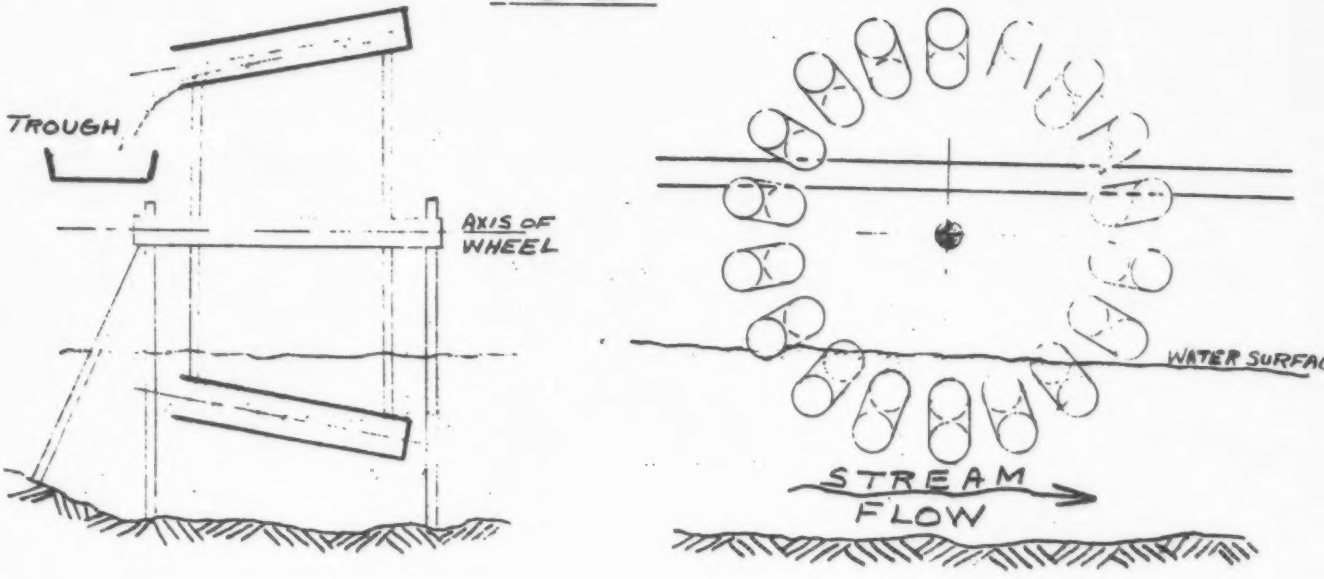
Tidal mills, using water wheels, were generally in the 30 to 100 kW size range, with these maximum power rating available for only relatively short periods of the tides. Tidal power is best adapted to situations where intermittent rather than constant energy output can be utilized. The tidal miller was required to keep odd hours. Existing large tidal plants are used to economically supplement large energy grids, and they can be used in conjunction with pumped storage where systems require high energy loads, for short periods of time. Small, low-head tidal plants could be similarly used for pumping domestic or industrial water from wells into elevated storage facilities for later use, or to recharge storage batteries from which a constant source of energy can be drawn.

Although detailed information on the theoretical height of tides is available for almost any location on the B.C. Coast, the predicted water elevations can be affected by up to several metres by unusually high or low pressures acting over the oceans, and by large wind storms. The potential for receiving tidal waves should also be considered in locating tidal installations. On top of the tides, wave height must be predetermined and superimposed in order that sufficient freeboard be maintained at the plant.

The marine environment is especially corrosive, with high humidity and dissolved salts in the atmosphere. All above water installations should either be constructed from inert materials, or if steel, be galvanized or paint protected.

Structures in the intertidal zone, alternately wet and dry, will deteriorate very rapidly unless protected cathodically. Water passages can become blocked by sea-weeds, and their hydraulic capacity adversely affected by both plant and animal growth. Where wave action is possible, structures must be very firmly constructed to withstand enormous forces, and debris which the waves cam cause to batter the structures should, if possible, be excluded.

FIG. 8.1


TROUGH
AXIS OF WHEEL
WATER SURFAC
STREAM FLOW

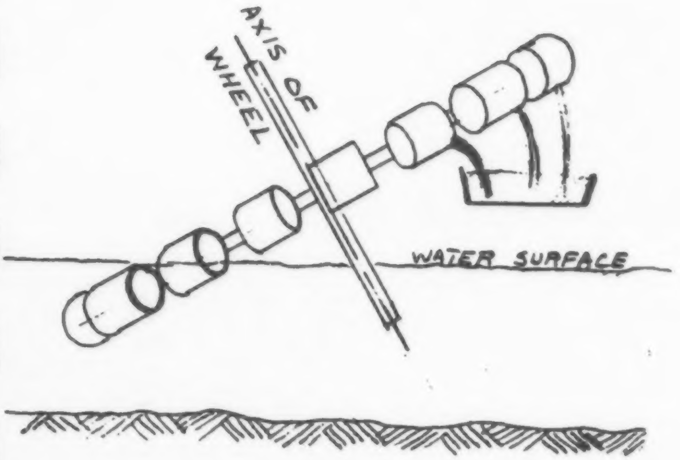

AXIS OF WHEEL
WATER SURFACE

FIG. 8.2

FIG. 8.3

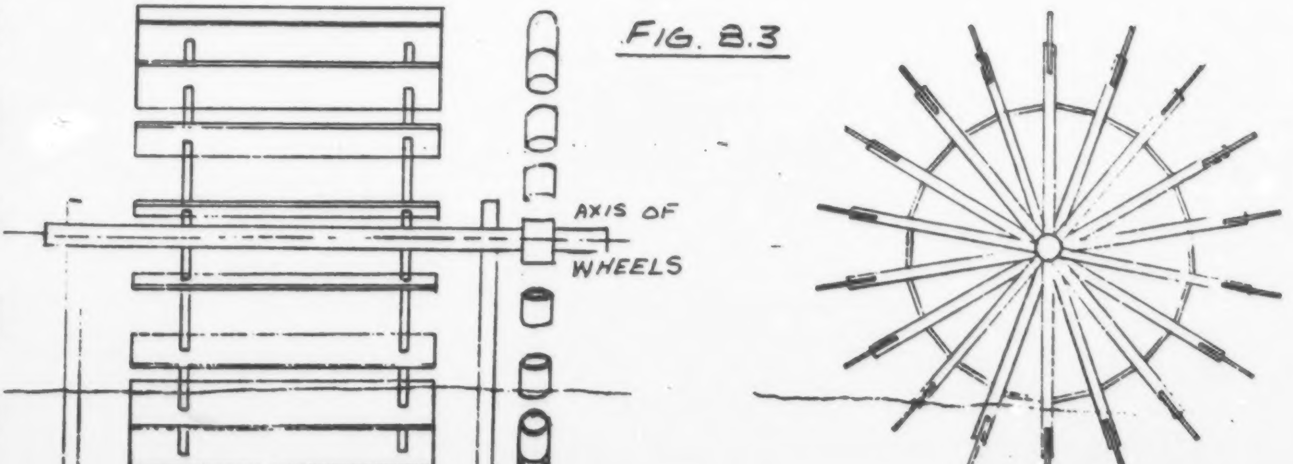

AXIS OF WHEELS
STREAM FLOW

FIG. 8.4

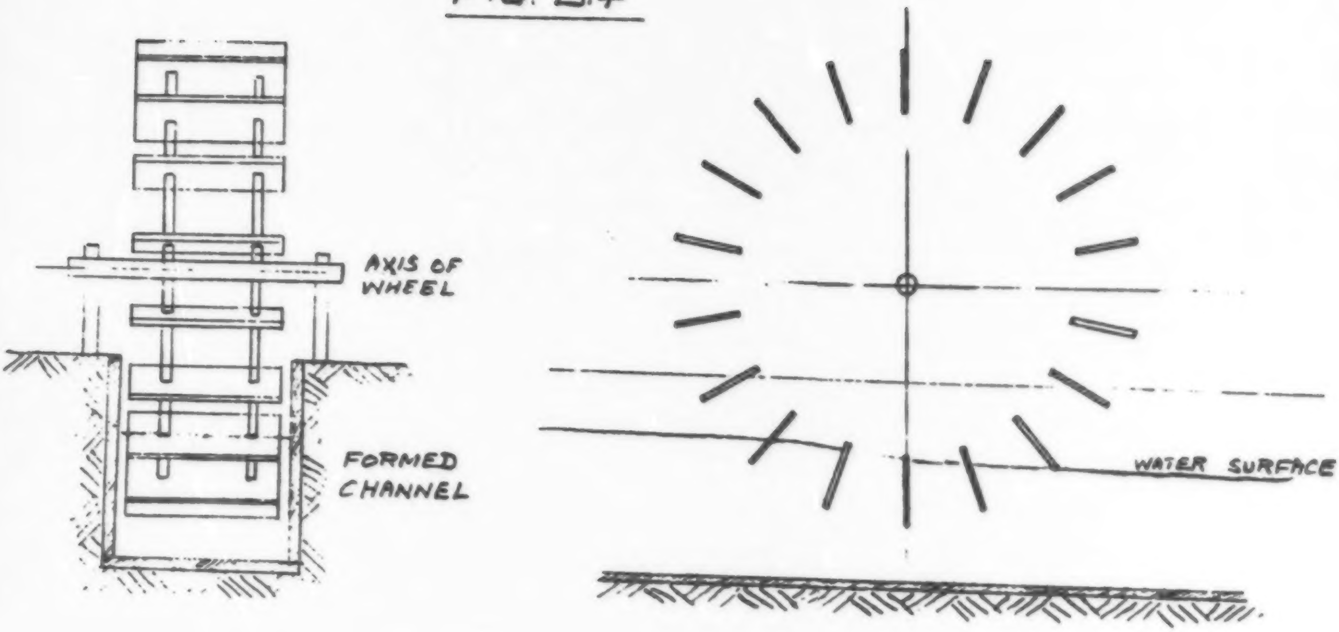

AXIS OF WHEEL
FORMED CHANNEL
WATER SURFACE

FIG. 8.5

(UNDERSHOT WHEEL)

Minimum head 0.3m (1 foot)

Efficiency range 25 to 45%

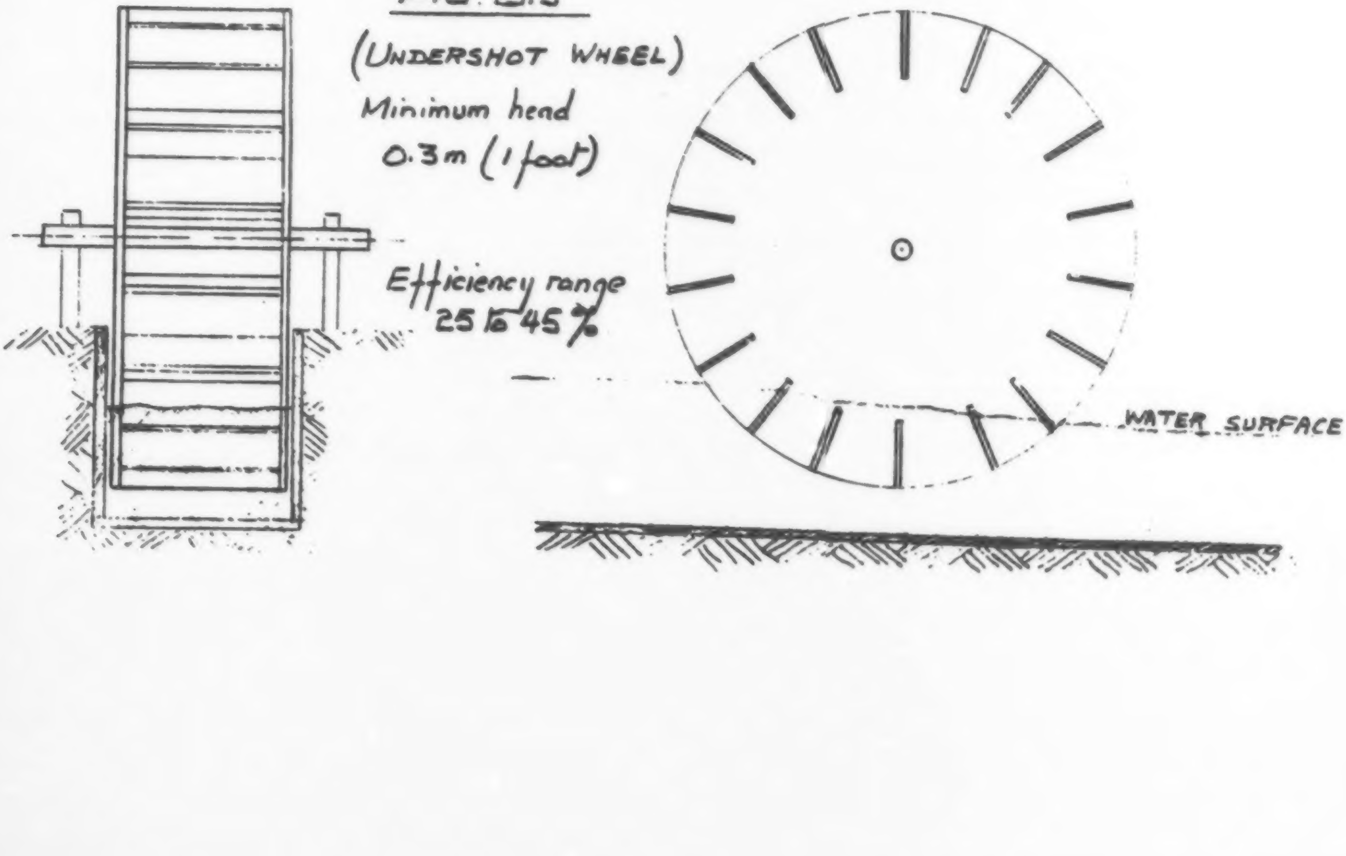
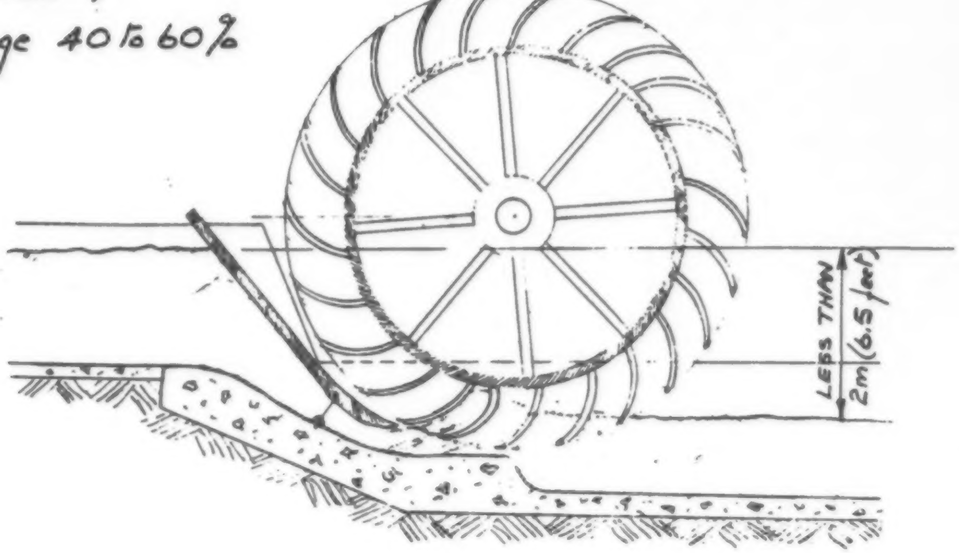

WATER SURFACE

FIG 8.6

(PONCELET WHEEL)
Efficiency range 40 to 60%


LESS THAN
2m (6.5 feet)

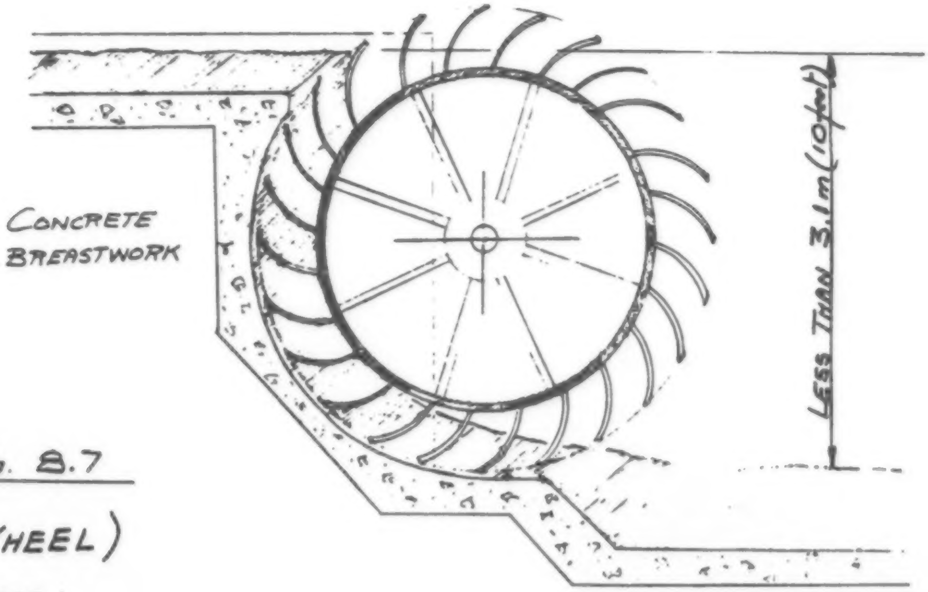
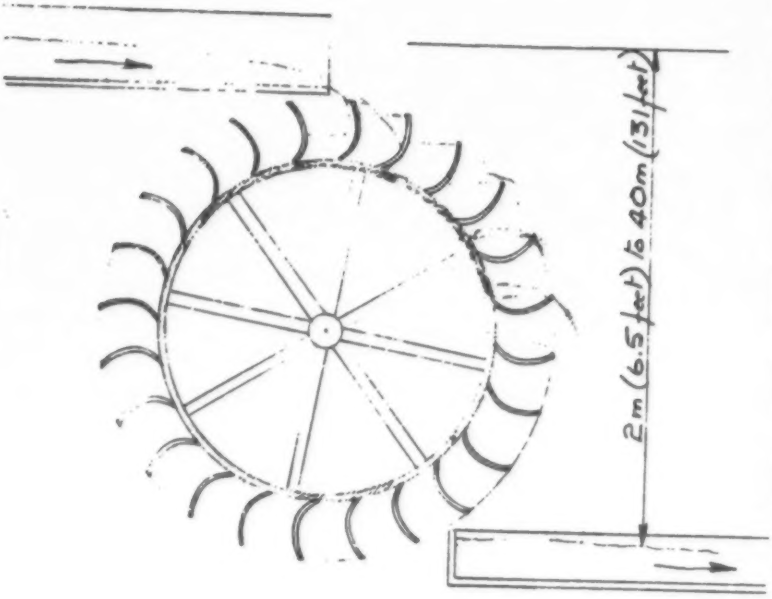
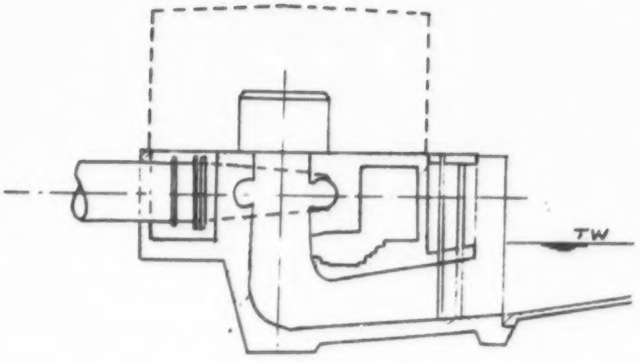

CONCRETE
BREASTWORK
LESS THAN 3.1m (10 feet)

FIG. 8.7

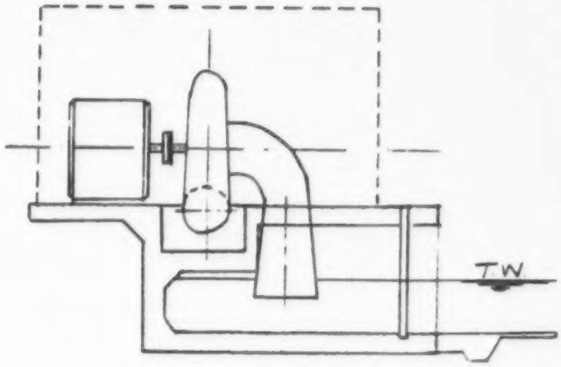
(BREAST WHEEL)
Efficiency ranges:
Low breast (water entering below wheel shaft) 35 to 40%
High breast (water entering above wheel shaft) up to 60%

FIG 8.8
(OVERSHOT WHEEL)
Efficiency range
60% to 65%
Rotational speeds from
20 RPM down.

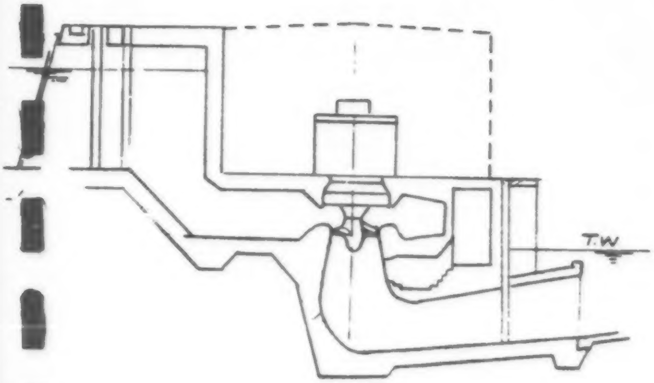

2m (6.5 feet) to 40m (131 feet)



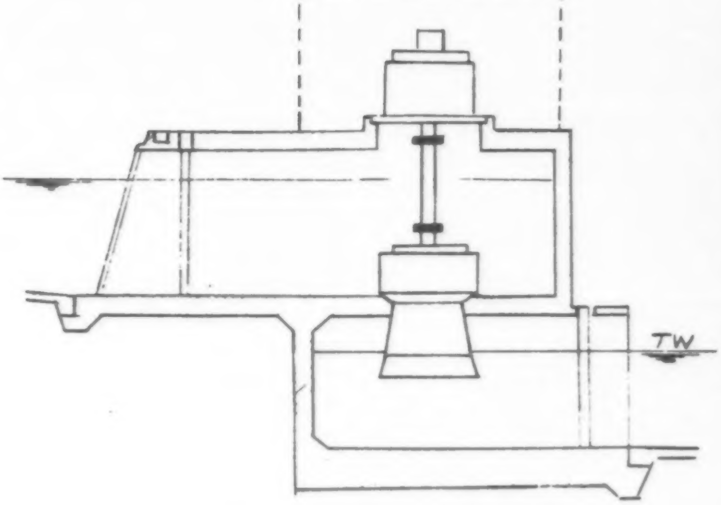
VERTICAL FRANCIS



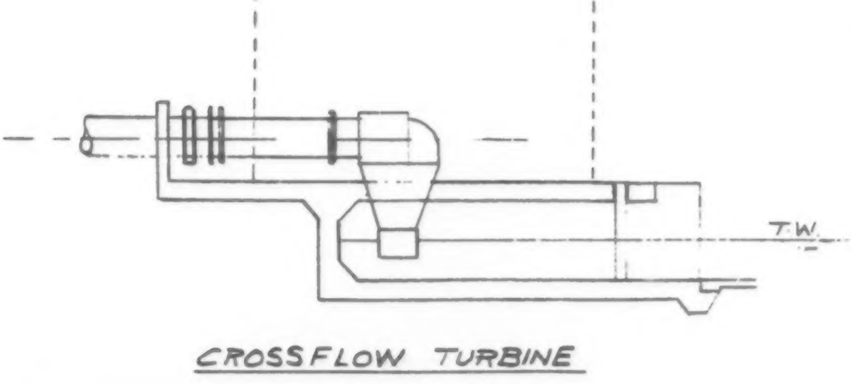
HORIZONTAL FRANCIS



VERTICAL PROPELLER

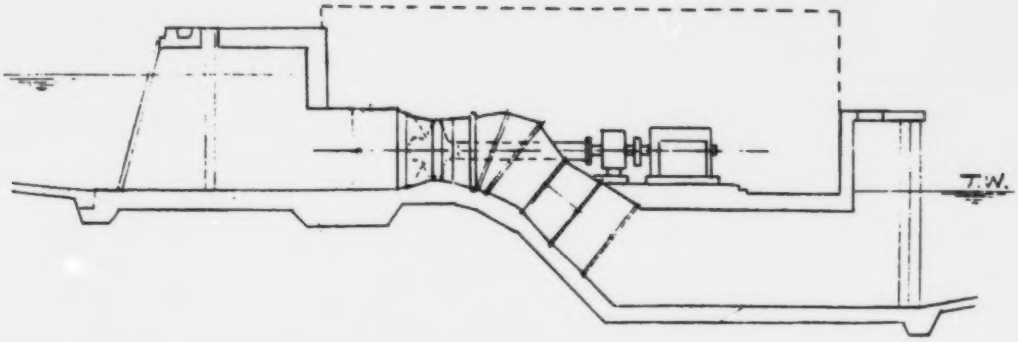


OPEN FLUME FRANCIS OR PROPELLER

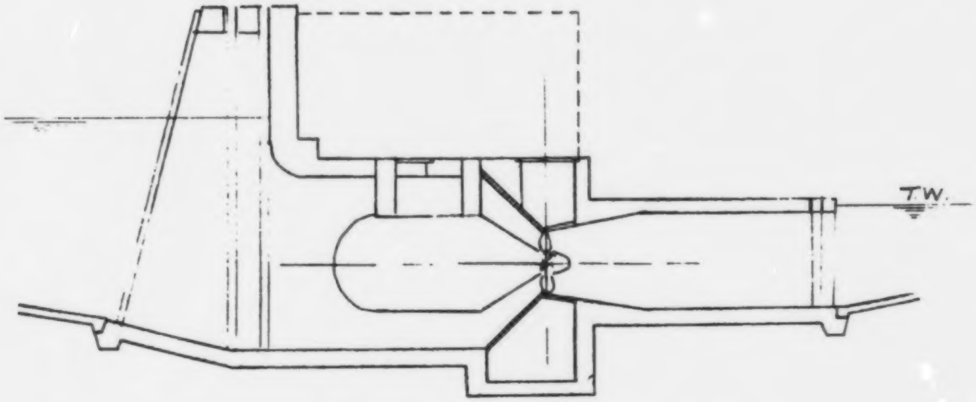


CROSSFLOW TURBINE

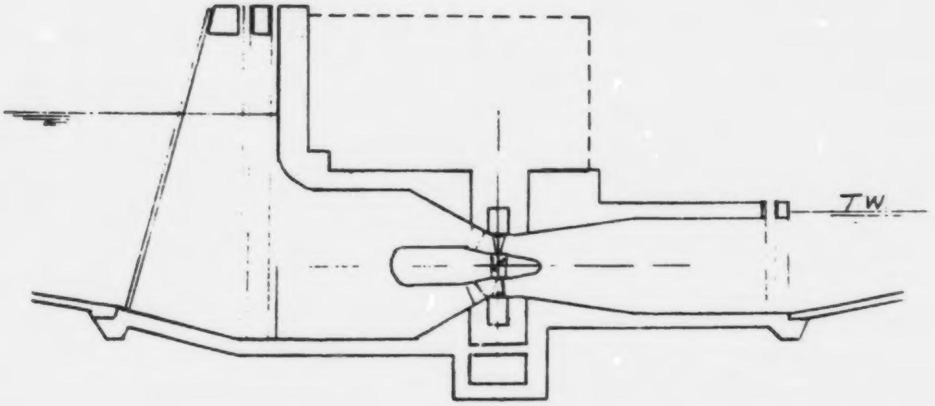
FIG 8.9



TUBULAR TURBINE

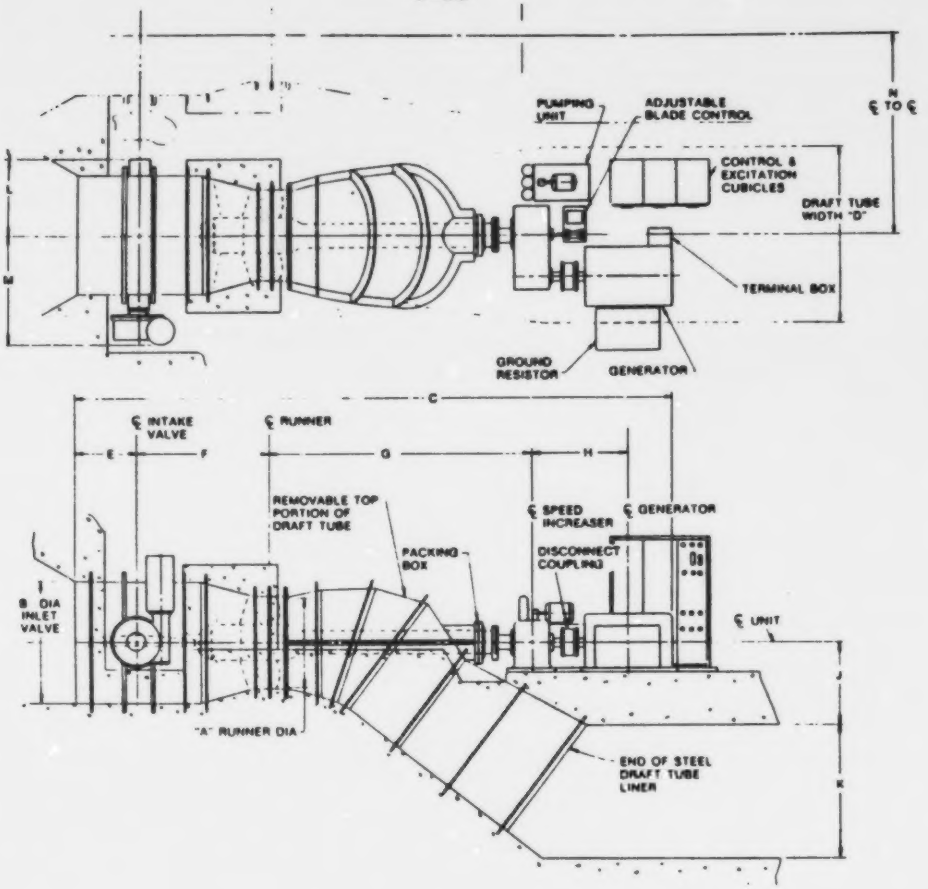


BULB TURBINE



RIM TURBINE

FIG 8.9 (CONT.)


PUMPING UNIT
ADJUSTABLE BLADE CONTROL
N
℄ TO ℄
CONTROL & EXCITATION CUBICLES
DRAFT TUBE WIDTH "D"
L
M
TERMINAL BOX
GROUND RESISTOR
GENERATOR
C
℄ INTAKE VALVE
℄ RUNNER
E
F
G
H
REMOVABLE TOP PORTION OF DRAFT TUBE
PACKING BOX
℄ SPEED INCREASER
℄ GENERATOR
DISCONNECT COUPLING
B DIA INLET VALVE
℄ UNIT
J
K
"A" RUNNER DIA
END OF STEEL DRAFT TUBE LINER

BASIC DIMENSIONS

A = Runner Diameter in millimeters (inches) = 1.00

All Other Dimensions Are In Proportion From Runner Diameter

A	750 (29.5)	1000 (39.4)	1250 (49.2)	1500 (59.6)	1750 (68.9)	2000 (78.7)	2250 (88.6)	2500 (98.4)	2750 (108.3)	3000 (118.1)
B	1.43	1.37	1.34	1.32	1.31	1.30	1.29	1.28	1.27	1.22
C	8.6	7.9	7.3	7.2	6.9	6.7	6.6	6.6	6.5	6.5
D	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
E	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
F	1.8	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4
G	3.8	3.6	3.5	3.5	3.4	3.4	3.3	3.3	3.3	3.3
H	1.5	1.3	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8
J	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
K	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
L	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7
M	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2
N	3.0	2.7	2.6	2.5	2.4	2.4	2.3	2.3	2.3	2.2

NOTE: Dimensions are approximate and may vary for specific applications.

Figure 8.10 Standardized Tube Turbine Dimensions, Allis-Chalmers

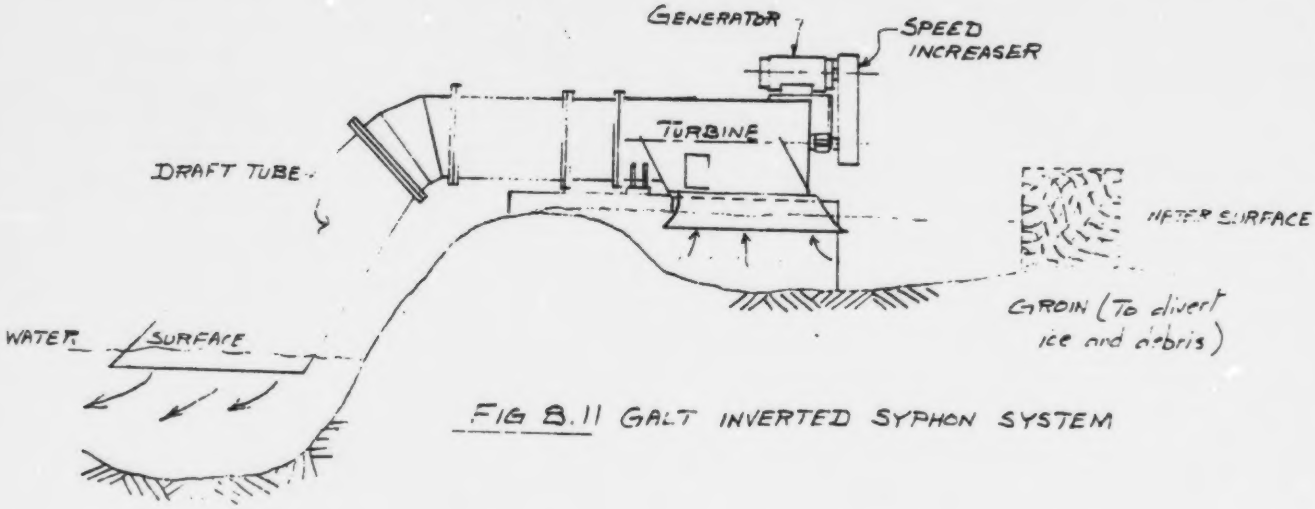

GENERATOR
SPEED INCREASER
TURBINE
DRAFT TUBE
WATER SURFACE
WATER SURFACE
GROIN (To divert ice and debris)

FIG 8.11 GALT INVERTED SYPHON SYSTEM

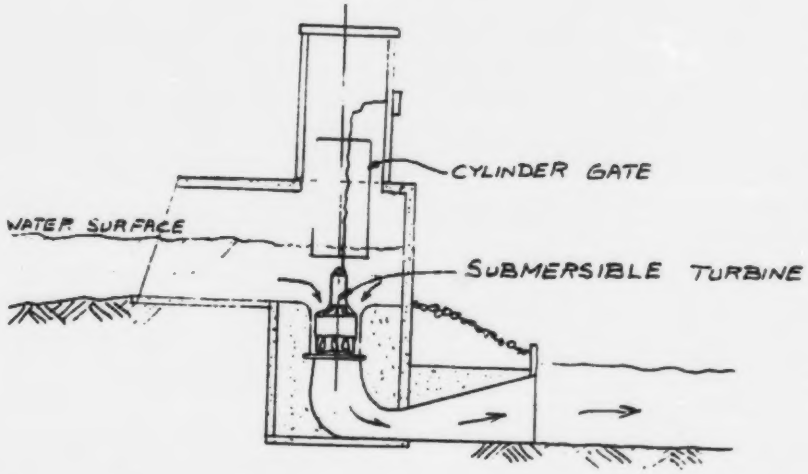

CYLINDER GATE
WATER SURFACE
SUBMERSIBLE TURBINE

FIG 8.12 FLYGT SUBMERSIBLE TURBINE

9. COLD WEATHER CONSIDERATIONS

9.1 CAUSE AND EFFECT

Dams have failed, intakes clogged, penstocks burst, valves seized, turbines worn, generators shorted, transmission lines collapsed and people have been injured at hydro-power installations. The causes are often a combination of just two circumstances: cold weather, and the failure to account for it.

Cold weather affects materials, people and plans. Materials, as they cool, change some of their characteristics. Water changes its state to ice at or about 0°C (32°F); metals and plastics become brittle unless specially formulated. All materials shrink unless held from so doing. People are required to dress more warmly and usually more restrictively, their field of view may be narrowed, their sense of feel is numbed, and their actions become less efficient. Tasks planned to be done easily in mild weather may become difficult or impossible to perform under conditions of cold. Hands may freeze to cold metal, concrete might not cure properly, painting or welding might require expensive and time consuming modification to complete.

In certain instances cold and its effects can be used to advantage. Clear, cold weather is often a good time to do trigonometrical survey work in the relative absence of heat distortion. Boggy ground can become passable when frozen, and lakes and rivers can be crossed on their frozen surfaces; or even aeroplanes can be landed on the ice if sufficiently thick. Ice cover can be a convenient platform from which to drill, or do depth soundings for underwater contours.

However, cold weather effects are by and large negative in that their consideration requires the expenditure of time, effort and money not required in other less severe climates.

9.2 CLIMATE

Climate varies considerably across British Columbia. Information on climate at a specific location in B.C. may be obtained from:

Air Branch Studies
Ministry of Environment
Parliament Buildings
Victoria, B.C.   V8V 1X4

Requests for information are best submitted together with a sketch showing the approximate extent, orientation and location of the installation proposed. Provincial or Federal government issued 1:50,000 scale mapping is available for most of B.C. and would form a good basis on which to sketch.

Information on climate is collected on a routine or sometimes spot basis at many establishments in British Columbia, often by government, but also by private companies and individuals. In most cases information required at a specific location will need to be inferred from information collected elsewhere. The confidence with which the inferences may be made will be considerably increased if any measurements are available from the site. As a basis for comparison, any such measurements should be included with the request for further information.

For planning and design, information on the complete range of probable and possible weather is required. Aspects particularly for considerations of cold weather are outlined in the following chart:

Type of Information	Purpose
Normal and extreme air temperatures by month, length and time or record.	General appreciation of site conditions for construction and operation planning.
Minimum air temperatures, and chances of their occurrence.	Structural design. Heating and insulation considerations.
Maximum expected rates of change in temperatures below 0°C (32°F).	Appreciation of sheet-ice induced loading.
Normal and extreme accumulated degree-days below freezing (Freezing Index).	Estimates of sheet-ice thickness.
Time and rates of snowfall.	Construction planning.
Accumulations of snowpack.	Structural and operational design.
Normal and extreme dates of ice formation and breakup on adjacent bodies of water.	Operation and construction planning.
Wind speeds, normal and extreme and predominant direction.	Structural design. Wind induced sheet ice movement and loading.

Although information specific to the site is required, some feeling for anticipated conditions may be obtained by reference to the following publications:

Department of Mines and Technical Surveys, Geographical Branch, "Atlas of Canada", Ottawa, 1977.

A.L. Farley, "Atlas of British Columbia", University of British Columbia Press.

W.G. Kendrew and D. Kerr, "The Climate of British Columbia and the Yukon Territory".

British Columbia Ministry of Agriculture, "Climate of British Columbia, Tables of Temperature, Precipitation and Sunshine".

Supplement to the National Building Code of Canada, "Climatic Information for Building Design in Canada".

Province of British Columbia, Ministry of Environment, Assessment and Planning Division, "A Summary of Climatic Regimes of British Columbia".

Figures from these and other sources are reproduced at the end of this chapter, but considerable caution should be exercised by the user, for reasons which include the following:

1. The figures are obviously at a small scale, and locating a proposed site accurately is difficult.

2. Lines drawn on the figures are of necessity very approximately located and may ignore some data. For example: mean annual snowfall at Daisy Lake Dam north of Vancouver averaged over many years of record is 400 cm (160 inches), whereas one might infer 250 cm (100 inches) from Figure 9.3.

3. Tables and figures are produced with some specific purpose in mind, and may not be applicable to the type of installation. For example: the National Building Code of Canada does not specifically apply to "hydro-electric dams and structures....." but information published in it may form the basis for the design of such dams and structures if the information is modified sufficiently to account for the different consequences of failure.

9.3 FROST

Moisture present in ground can freeze and thaw with air temperature variation, the depth from the ground/air surface at which freezing occurs being related to the "Freezing" Index, see Figs. 9.1 and 9.2.

Freeze/thaw causes swelling and contraction of the ground. In generally horizontal ground, the surface will rise and fall (frost heave), but at depressions or cuts in the ground surface, say at river banks, surface movement can have considerable horizontal components. A structure or building sitting on ground subject to freeze/thaw will move unless restrained. If the nature of the ground varies under a structure, say part rock and part gravel, differential movement will occur and the structure will either tip (rotate), or be considerably stressed. It is usually best to locate a structure on a uniform foundation. A free-draining ground will be least susceptible to freeze/thaw.

To eliminate movement due to freeze/thaw, structure foundations should be below the limit in Fig. 9.2. Care should be taken that, in excavating to this depth, the exposed sides and bottom of the excavation are not subjected to frost penetration which will become a problem upon subsequent thawing. Either the excavation should be made during mild temperatures, or the exposed surfaces should be blanketted by some means until the foundation is in place. Backfill in contact with such foundations should be well drained, because if the backfill material freezes to the foundation walls, it could lift and crack the walls, as well as exert pressure on them. Covering the foundation walls with a bond-breaker will help keep the movements of the foundations and backfill independent, and reduce some of those pressures.

In some locations the ground is permanently frozen to great depth, and freeze/thaw occurs only at the surface. This condition of permafrost can exist at higher altitudes a great distance south of the southern limits shown on Figure 9.4. Introducing structures into such ground requires special considerations.

First, the ground itself may have to be excavated by unusual methods. Heating the ground might make excavation easier, but the ground should be allowed to re-freeze before placing foundations. Frozen ground will stand unsupported at steep slopes, but the exposed surfaces must be guarded against thawing.

If heat can flow from a structure into the frozen ground where it is buried, the possibility exists of the ground thawing, and the structure either floating or sinking. If melted water can drain from around the structure, piping of the ground material, and unexpected settlement can occur. Some structures, such as utility pipelines, are not possible to be effectively insulated, and therefore they must be placed above ground.

9.4 COLD WATER

Pure water is denser at about 4°C (41°F), and dense water sinks through less dense water.

Figure 9.5 shows the temperature at different depths in a lake, and the changes during Fall, as the air temperature cools the surface and ice forms.

Currents will move vertically through the water as the surface water cools and sinks to its equilibrium position. This could occur in a relatively short space of time, causing considerable agitation at the surface. The surface water temperature will always lag behind the air temperature until all of the water has been cooled to its maximum density, then cooling of the surface water will be relatively rapid and ice will form.

One method of delaying the formation of ice, or slowing its rate of growth, or thawing it, is to bring the relatively warmer water to the surface. This is done naturally by springs which occur in lake bottoms and which in certain circumstances of geothermal activity will keep ice from ever forming; or artifically, by allowing compressed air bubbles to rise through the water and literally drag up the warmer water.

In larger undertakings the mass of relatively warmer water below the reservoir surface may be used to inhibit or control ice growth downstream of the reservoir by drawing it off and releasing it into the stream, in some cases allowing year-round river traffic where the river had historically frozen, or mitigating the potential hazards from the build-up, and subsequent failure, of ice dams.

9.5 ICE

When water freezes, it increases its volume about 9 percent, and decreases its density by a similar amount, and therefore the resulting ice floats. In still, or tranquil flow, freezing occurs at the air/water surface, and plate or sheet ice forms. In turbulent water, where air is introduced by mixing, or where the flow path rapidly contracts and expands around obstructions, ice can form at any depth where the water becomes "super cooled" to below 0°C (32°F). Under such circumstances "frazil" ice, which often appears cloudy under the surface, forms and readily adheres to itself or any other convenient surface. Each of these basically two forms of ice must be considered.

9.5.1 Sheet Ice

Sheet ice will form, and keep forming for as long as the air temperature is below 0°C (32°F). Its maximum thickness is related to the Freezing Index at a location; and is given approximately by the formula:

$$\text{Maximum Ice Thickness (metres)} = 0.036 \times \sqrt{\text{Freezing Index (°C)}}$$

$$[\text{Maximum Ice Thickness (inches)} = \sqrt{\text{Freezing Index (°F)}}\,]$$

Example: Freezing Index = 2000 day °C

$$\begin{aligned}\text{Maximum Expected Ice Thickness} &= 0.036 \times \sqrt{2000} \\ &= 1.61 \text{ m (64 inches)}\end{aligned}$$

The rate at which ice forms increases with lower air temperature, but decreases with increased ice thickness. It also decreases with increased insulation of the ice surface, which could be by natural snow cover, artificially induced snow cover, or some other material covering, such as straw.

As soon as it forms, ice is subject to the frictional drag of the water flow beneath it, and the air flow above it. The smoother the ice, the smaller will be those forces per square metre of surface, but considering the total surface involved, the forces can become substantial (on larger lakes many thousands of tons). These forces do not depend upon ice thickness, but their effect doestne ice is free to move. Thin ice, with less inertia, will be moved more easily than thicker, heavier ice, and will attain higher velocity more quickly. However, when it fetches up against a structure, the thiner ice will probably not exert as much impact force, as it will crack and buckle more easily. In most cases if ice forms it is not free to move, but under certain circumstances, the ice is set free, and these forces can be brought into play.

A water intake or other structure can usually be set back from a potentially large sheet of ice, and some effort can be made to keep ice and its effects from the structure by the following means:

(a) manually breaking the ice and removing it while it is still a manageable thickness if labour is available and safe access provided;

(b) using a boat to keep the ice broken;

(c) blanketting the ice with snow or straw or some other insulating material to slow the rate of growth, and keep the ice thin;

(d) introducing warm water to the surface (bubbling air, pumping water) to inhibit ice growth;

(e) directly heating the water surface using warm air blowers or infrared heaters;

(f) covering the intake area to trap warmer air; or

(g) heating the surfaces against which ice would otherwise form: (induction heating of metals; heating wires in concrete; radiant heating of exposed back faces of gates; passing hot air, water or oil through embedded coils or hollow sections).

Air temperature changes will induce temperature changes in ice, and the ice, if free to do so, will expand or contract by an amount equal to: .00016 times any dimension for each degree Celcius change in temperature (0.000089 for each °F).

> Example: 100 m (328 feet) length of ice, air temperature drops from -5°C (23°F) to -15°C (5°F). Change in length = 0.00016 x 100 m x 10°C = .16 m. (or .000089 x 328 feet x 18°F = 0.53 feet).

A structure embedded in, or attached to, an ice sheet must be capable of deflecting sufficiently, or resisting the movement. The amount of force ice can exert under these circumstances depends upon the consistency of the ice, its thickness, the temperature gradient through it, the rate of gradient changes (related to the rate of change of air temperature) and the amount of restraint on the ice sheet. As can be seen from Fig. 12 forces of several thousands of pounds per linear foot (tonnes per linear metre) could be required to be accommodated.

Sudden fluctuations in the surface of the water supporting the ice can cause large uplift or downpull on structures to which the ice adheres. Water from an unseasonal melt, or water released into the reservoir when an ice-dam gives way, could cause buoyancy forces on the ice to be transmitted to the structure.

Drawdown of the reservoir can leave ice hung up on the structure. In these circumstances the ice behaves plastically, gradually deforming to regain its equilibrium. The forces involved depend not only on the conditions of the ice and the configuration of the situation, but the speed at which the events occur. Sheet ice/structure interaction is often an involved study, and if at all possible, elimination of this type of interaction usually pays.

9.5.2 Frazil Ice

Frazil ice is the ice which can form at any depth in moving water, given the right circumstances. Rivers in British Columbia have become completely dammed by frazil ice, resulting in upstream flooding, and when the dams break, downstream flooding.

As turbulence is a contributing factor in introducing cold to the water, one method of eliminating, or at least reducing the formation of frazil ice, is to make the watercourse less turbulent. Widening, and deepening a watercourse would do this, as well as removing boulders and other items which cause the flow to deviate. Slowing the flow gives the ice more time to float to the surface where at least it can be seen, and possibly melted. Removing boulders or stumps, or waterlogged trees from the watercourse as well as removing potential areas of ice formation, also removes potential surface to which it might adhere and grow. Water flowing uniformly at no more than 0.6 m/s (2 f/s) usually does not support the formation of frazil ice.

If frazil ice does form and floats downstream, then the intake must be planned to either exclude it, or otherwise deal with it. Exclusion might be achieved by siting the intake such that the ice floats by, but the hydraulics involved must be carefully thought out so that the shape chosen does not draw in the ice, with the water.

If the ice is present only on the water surface, it might be caught on an upstream log-boom to be dealt with more conveniently, or deflected from the intake by means of a skimmer or obliquely angled surface extending down over the intake to a sufficient depth to account for both the water elevation changes and the thickness of the frazil slush.

Vortexing, the swirling of water around a column of air, must be especially avoided at intakes intended to operate in cold weather. Not only does the vortex speed up the water and introduce air at depth, but it also supplies the mechanism for drawing any formed ice down into the pipeline, where it becomes increasingly hard to deal with. Vortexing can be avoided either by drawing water from well below the surface, or by providing a floating cover over the intake, or providing guides to inhibit the swirling motion. In cold climates one should aim for sufficient depth of submergence as neither of the other two methods mentioned will eliminate potential ice problems.

Most water intakes in British Columbia require trashracks to limit the size of materials entering the water passages. The racks partially block the flow, cause turbulence, and may require special attention to prevent either the formation or build-up of frazil ice on them. Various forms of heating racks, direct heating of metal racks by induced electrical current, or hot water, oil or steam passed through hollow rack sections have proven successful. Frazil ice has less tendency to adhere to wood and plastics than metals. Paints have been developed which appear to cause at least partial immunity to frazil ice build-up.

In view of the uncertainties with regard to the location of frazil ice formation, and the probability of a breakdown in whichever systems are put in place to handle it, smaller intake structures should be designed not to fail under conditions of full blockage.

When insufficient water is reaching the turbine the cause can be investigated, but a failed intake can cause all sorts of materials to be ingested into the water systems with potentially expensive consequences.

Once in a penstock, frazil ice is likely to stick anywhere along the sides, but most likely at bends, joints, couplings, inspection ports, valves and branches, where turbulence may enhance its growth. The buoyant ice will tend to float to the top of the pipe, and collect there, blocking the air bleed and intake valves located at high points along the pipe. Other water control valves along the pipe can become locked by ice.

The small nozzles of pelton turbines may be instantaneously blocked by lumps of ice, resulting in an internal penstock pressure of up to twice the static head. Other turbines are less susceptible to this form of blockage; the cross-flow types claim to be almost immune.

Frazil ice sometimes attaches to anchor or bottom ice which has formed on the river bed, and can lift particles from the bed, and carry them along, greatly increasing wear on penstocks and turbines. Even with the ice itself melting along the way, the particles can scour the pipes and the turbine blades at which they are directed.

Leaving the turbine, flow is again very turbulent, and frazil ice can form in the tailrace. As with the intake, the velocity of the water should be kept below 0.6 m/s (2 f/s), and the flow made as tranquil as possible. It would help to enclose the tailrace, and possibly provide heating to the enclosure to move any frazil ice problem downstream of the installations.

9.6 THE WATERSHED

In many areas of British Columbia much of the total annual precipitation falls as snow, and is held in that form throughout the winter, until warmer spring temperatures melt the snow. The date of release of spring water may vary considerably, and plans to deal with the water should be flexible enough to take this into account.

9.7 THE DAM OR DIVERSION STRUCTURE

The structure will create a pond of water often where none existed previously, therefore creating the possibility of sheet ice formation where none was known previously. Rockfill structures are inherently massive, and may not require modifications to accept sheet ice loading, but most other types of structures must be carefully designed if such loading can occur. Especially vulnerable are 'flash board' type structures sometimes added to existing dams to increase pondage: as cold air circulates behind the boards, freezing of water adjacent to the boards is made more likely. It is prudent to maintain winter water levels below such structures, by having spill occur at a level far enough below the relatively weaker structures so that ice forming will not affect them.

Some diversion structures will be provided with low-level outlets to allow draining of the pond, and possibly flushing of its accumulated sediments. If a valve, when activated produces a spray which can freeze, the value should be operated judiciously during cold weather. If the plant is not intended to be operated during winter, and the intake pond is left draining, the drain should be monitored for at least one winter of operation to check the effects of the cold weather.

9.8 INTAKE STRUCTURE

The expected thickness of sheet ice may be calculated, and the intake designed to be capable of operating below the level of that ice floating in the forebay. The thickness of frazil slush which can coalesce at the surface is impossible to predict, especially if the frazil accumulates below the sheet ice. Making the pond as big as practical will encourage the frazil to surface away from the intake, where it poses less of a threat.

9.9 CANAL

A canal operating with an ice cover has different hydraulic characteristics from one operating with a free water surface, and account must be taken of the water friction against the underside of the ice. The walls of the canal must be capable of accepting loading from the expanding and contracting ice cover.

When the ice on the canal melts, or rather breaks up, some provision should be made at the downstream end of the canal to prevent the floating ice hampering the operation of an adjacent intake. It might be possible to flush the ice away by allowing a surge of water into the canal and ceasing operation of the plant whilst the surface ice is further loosened, then carried along and passed over a downstream spillway.

9.10 PENSTOCKS

Water passing along a pipe gains heat created by the friction of its passage, but at the same time loses heat to the pipe if the pipe is colder than the water. When heat loss exceeds heat gain, water remaining in the pipe will eventually freeze. In winter operation the water entering a penstock is often just above freezing, and the rate of heat loss coupled with the time the water remains in the pipe is critical.

Heat gain through friction is proportional to the square of the water velocity. Heat is lost through the wall of a pipe at a rate proportional to the conductivity of the material. Relative conductivities of various materials are:

Wood Stave	1
PVC	1
Polyethylene	2.5
Asbestos Cement	4
Concrete	5
Ductile Iron	385
Steel	420
Aluminum	1410

Heat is conducted through steel 420 times as easily as through wood.

Heat is also lost from the outer surface of the pipe by radiation, and convection. The relative powers of typical surfaces to emit heat by radiation are:

Aluminum	1
Cast Iron	1.7
Wood	2.2

Convection loss increases with wind velocity, by factors of 3.7, 5.1, 6.2 and 7.1 for velocities of 10, 20, 30 and 40 miles per hour, respectively, compared to 1 for still air.

Under given combinations of materials, temperatures and flow rates, heat gain and loss quantities can be calculated, but the foregoing figures give some indication as to which materials and conditions will be more likely to result in the formation of ice, and which combinations should help alleviate that possible condition.

Cold weather considerations for penstocks include:

1. The higher the velocity of the water through the pipe, the greater the heat gain, and less time the water spends passing through the pipe.

2. Reducing or removing cold air blowing over and around the pipe will considerably reduce both radiation and convection losses. Siting the penstock through mature woods or along some sheltered route would help reduce wind cooling effects.

3. Surrounding the pipe with an insulating material would reduce conduction losses: that extra insulation could economically be more thickness of the original material, or a different material requiring its own purchase and installation costs.

4. Burying the pipeline removes air flow and introduces an insulating material, the backfill, and the possibility of further insulation through snow cover. Depending upon the terrain and nature of the ground requiring excavation burying pipeline can be an initially costly alternative, but on occasion, has been found to be the only viable alternative for year round operation.

5. Air bleed and intake valves should be well insulated, possibly enclosed in removable covers. In areas of high snowfall a passage for the air should be kept open at all times.

6. Water leakage can occur at mechanically coupled joints, and between wood staves. The pipe should be checked and leakage stopped or dealt with, or resulting ice build-up can leave the joints ineffective, or introduce some other hazard.

7. Allowance should be made at supports and joints for the shortening of pipes due to both internal pressure and cold temperatures.

8. Pipes should be checked to ensure that where applicable they can support snow loads, both with the pipes full and under pressure, and with the pipes empty.

9. Water passages should be drained if the installation is shut down even for short periods during winter; the inconvenience will be worth while.

9.11 POWERHOUSE

The powerhouse must obviously be sufficiently strong to resist snow and wind loads. A steeply pitched roof will shed much of the snow load, but can attract increased wind load. Doors and windows should be weatherproofed to prevent blowing snow from entering the building.

Ventilation should be provided through some means which will allow continued operation in spite of snow build up. The inside of the powerhouse should be well drained to handle leakage and condensation. The drains should be either insulated by being buried deeply, or heated either by electrical heat tracing or by direct heat. The water must leave the powerhouse, and some ingenuity may be required to prevent blockage of the outfall. One method is to bury the outfall in a well drained granular material. Condensation will form on the bare metal outside the water passages within the powerhouse, unless the surfaces are coated with particularly formulated paints, granulated cork, or some other insulating material.

To help maintain the interior temperature, leave light bulbs burning, and supplement this by radiant heaters directed towards the machinery. A ceiling fan would help circulate the heated air to where it is most needed.

During unscheduled winter shutdowns, secondary power sources, such as batteries or generator, should be available to prevent freezing in the powerhouse.

9.12 TRANSMISSION LINES

The lines should be located bearing in mind the possible changes to the ground profile brought about by standing and drifting snow, and sufficient clearance should be left under the lines to account for this situation. Lines should be well clear of trees which can bend and topple under snow cover. Intense cold causes the lines to contract, and sufficient slack to account for this (see Chapter 4), should be incorporated when stringing the lines, or the resulting tension will pull poles out of place and strain supports. Guy lines to poles should be made as visible as possible against the white background; split orange coloured pipe or fluorescent orange paint extending to well above the expected snow cover could be used.

9.13 ACCESS

Safe access should be assured to any location requiring attendance during the operation of the installation. Pathways, and especially steps, should be adequately drained to prevent icing over, and rope handlines should be provided where required. Trail markers should be obvious whenever they might be required, during all weathers, day or night.

Door locks must not freeze, and doors should open inwards if standing snow is likely to be a problem.

9.14 CONCLUSION

Designers, owners and operators are fortunate in the shared knowledge that much of what can go wrong with hydro-electric installations already has.

It is possible that attempting year round operation of a facility would not be cost effective, and some plants cease operation for part of the year.

Cold weather contributes its own unique problems, but with careful consideration of the nature of those problems, a successful installation can be planned, designed, constructed and operated profitably.

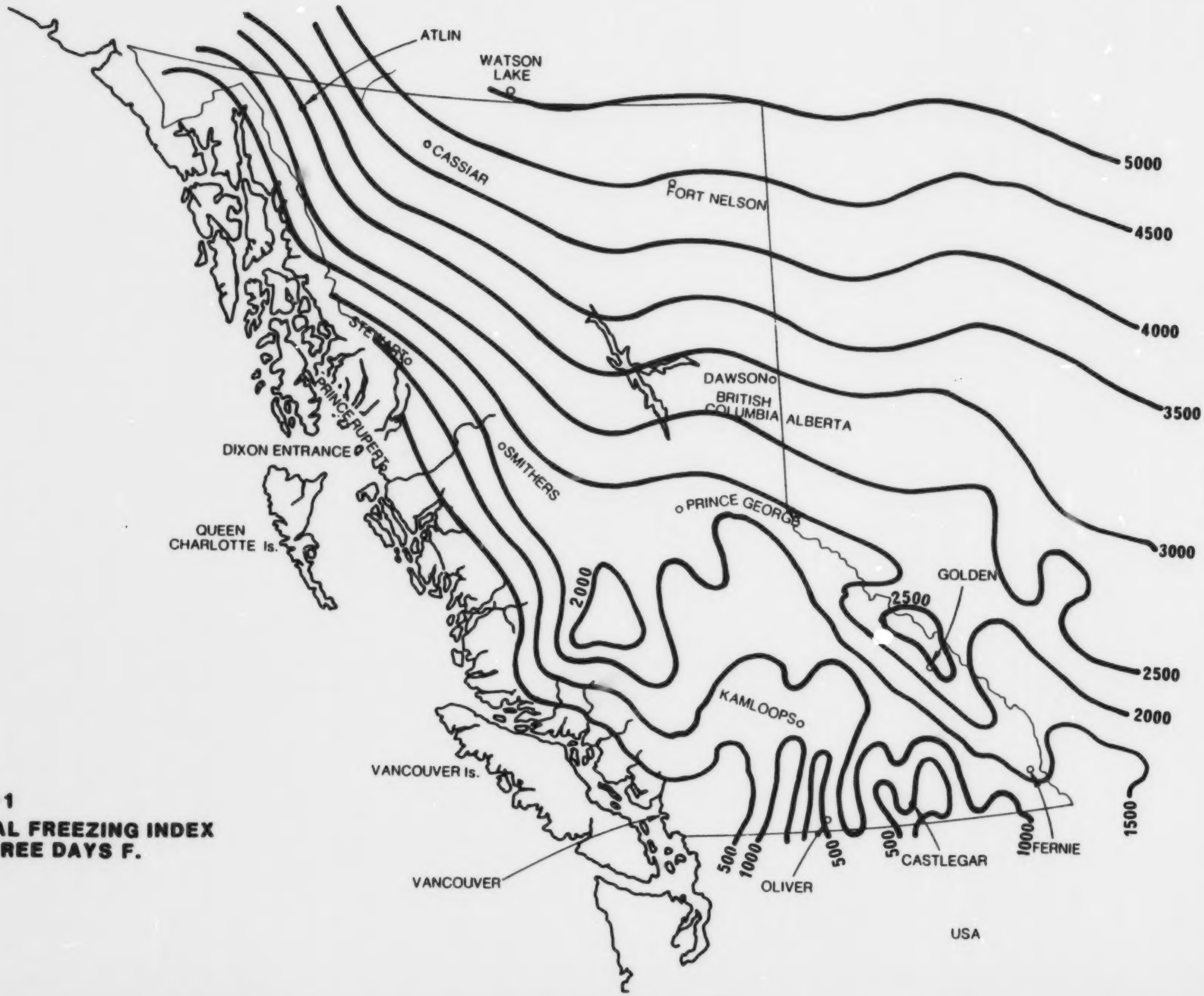

ATLIN
WATSON LAKE
CASSIAR
FORT NELSON
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
DAWSON
BRITISH COLUMBIA
ALBERTA
STEWART
PRINCE RUPERT
DIXON ENTRANCE
QUEEN CHARLOTTE Is.
SMITHERS
PRINCE GEORGE
GOLDEN
KAMLOOPS
VANCOUVER Is.
VANCOUVER
OLIVER
CASTLEGAR
FERNIE
USA

FIG.9-1
NORMAL FREEZING INDEX IN DEGREE DAYS F.

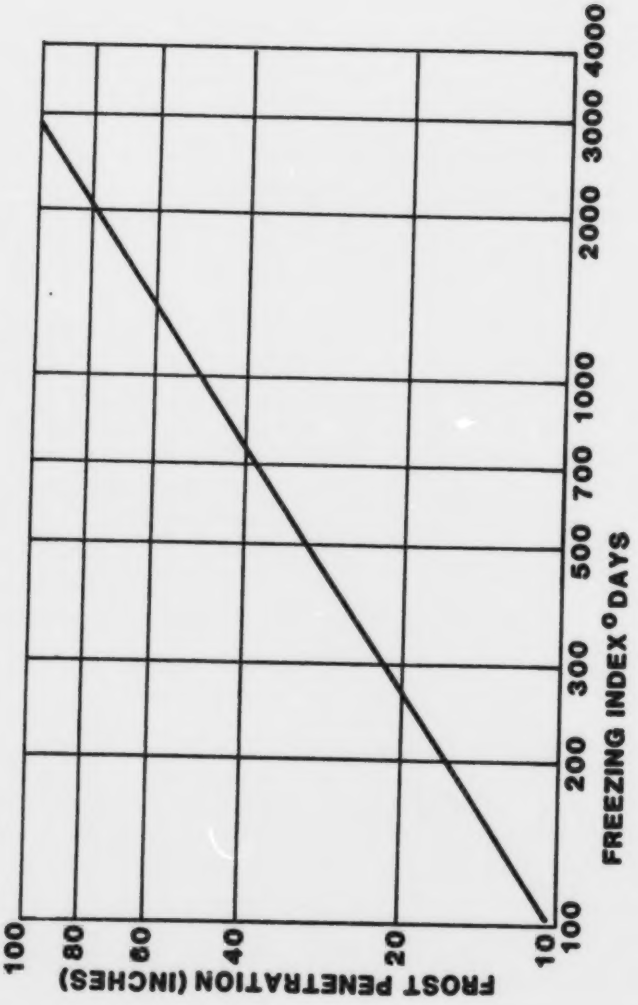

FROST PENETRATION (INCHES)
100
80
60
40
20
10
100
200
300
500
700
1000
2000
3000
4000
FREEZING INDEX °DAYS

FIG.9-2

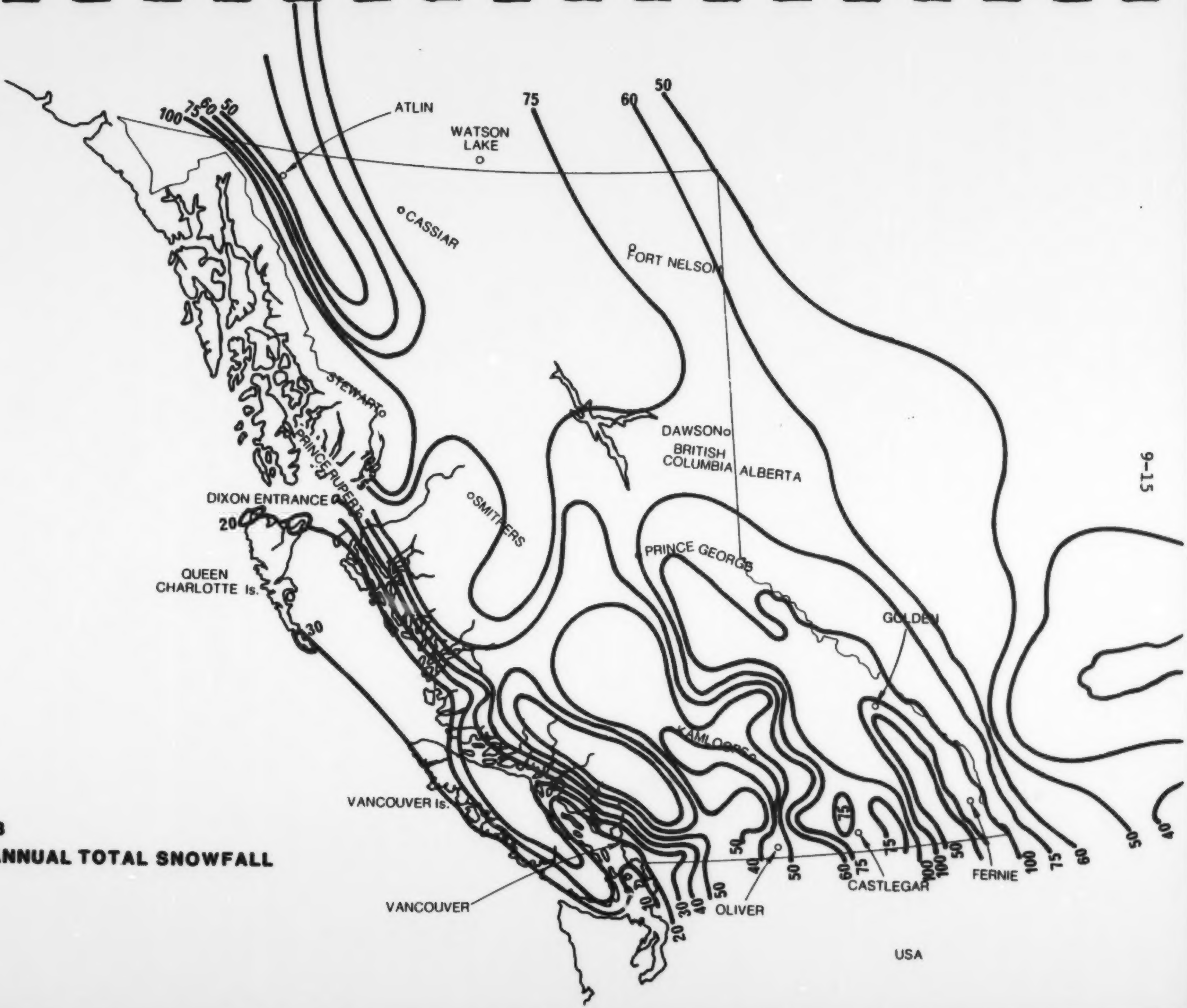

ATLIN
WATSON LAKE
CASSIAR
FORT NELSON
STEWART
DAWSON
BRITISH COLUMBIA
ALBERTA
SMITHERS
PRINCE RUPERT
DIXON ENTRANCE
QUEEN CHARLOTTE Is.
PRINCE GEORGE
GOLDEN
KAMLOOPS
VANCOUVER Is.
VANCOUVER
OLIVER
CASTLEGAR
FERNIE
USA
100
75
60
50
40
30
20
10

FIG.9-3
MEAN ANNUAL TOTAL SNOWFALL

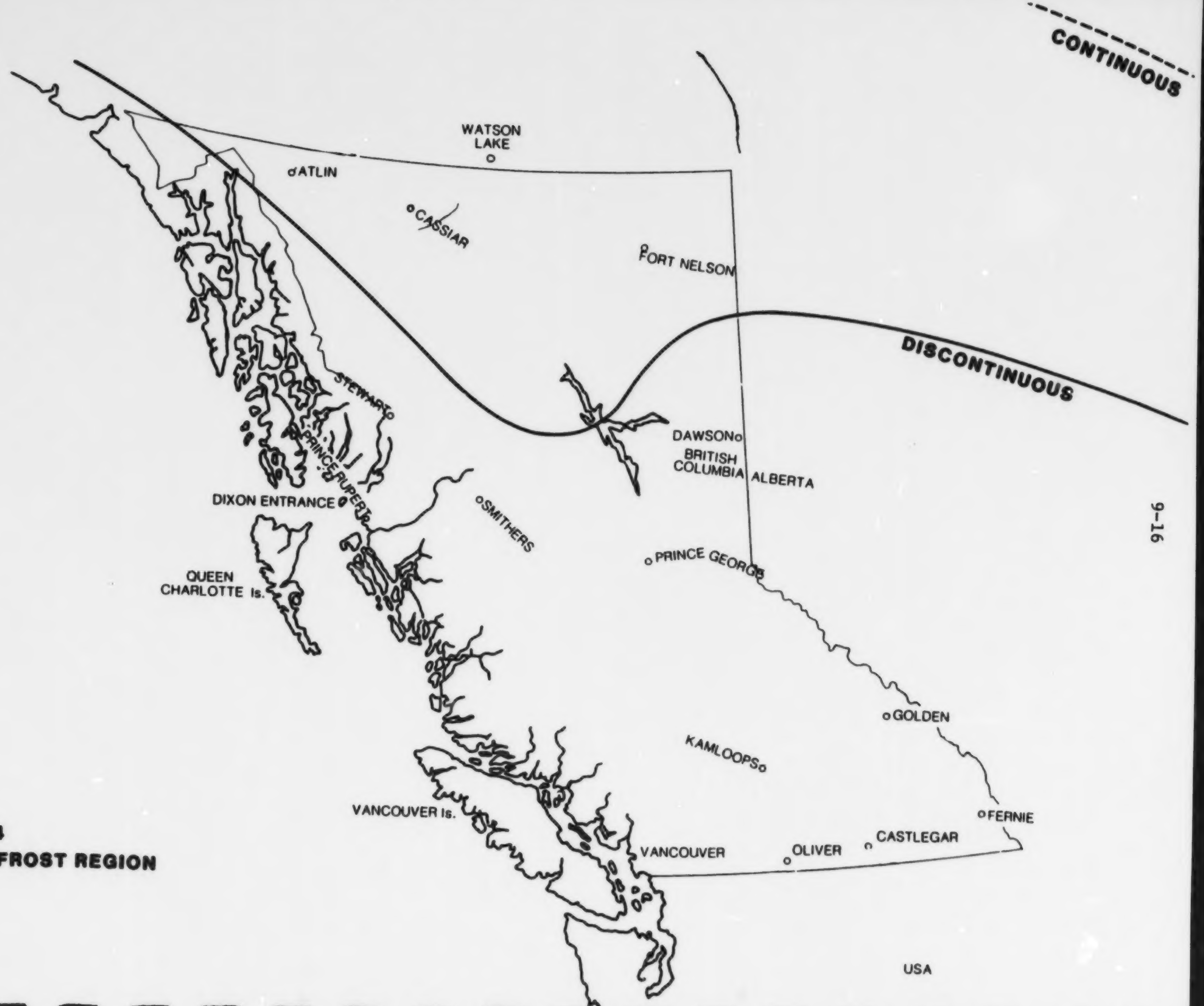

CONTINUOUS
DISCONTINUOUS
WATSON LAKE
ATLIN
CASSIAR
FORT NELSON
STEWART
PRINCE RUPERT
DIXON ENTRANCE
QUEEN CHARLOTTE Is.
SMITHERS
DAWSON
BRITISH COLUMBIA
ALBERTA
PRINCE GEORGE
GOLDEN
KAMLOOPS
VANCOUVER Is.
VANCOUVER
OLIVER
CASTLEGAR
FERNIE
USA

FIG.9-4
PERMAFROST REGION

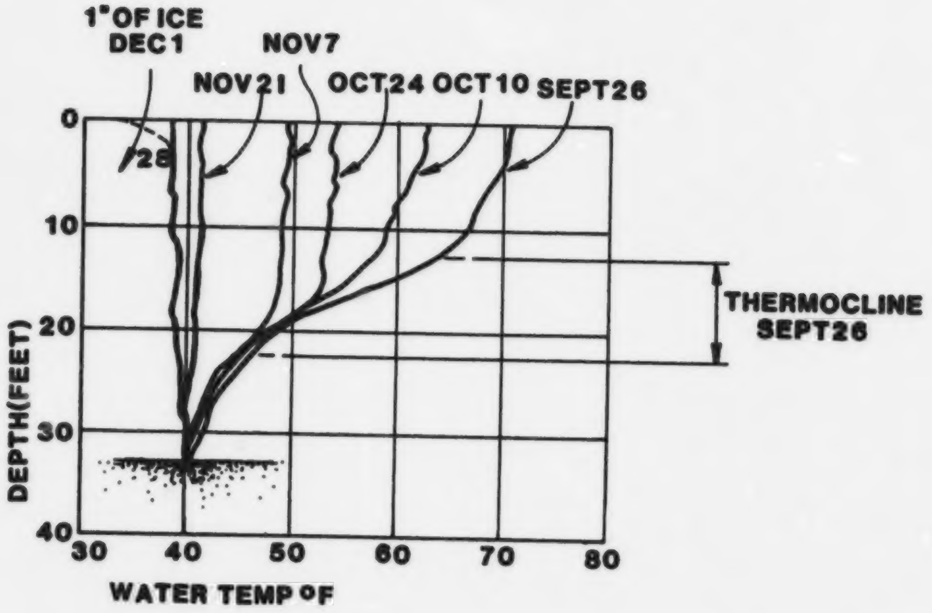

1" OF ICE
DEC1
/28
NOV7
NOV21
OCT24
OCT10
SEPT26
THERMOCLINE
SEPT26
DEPTH(FEET)
0
10
20
30
40
30
40
50
60
70
80
WATER TEMP °F

FIG.9-5

10.0 ORGANIZATION AND OPERATION OF A PUBLIC UTILITY

10.1 INTRODUCTION

This chapter outlines the regulatory conditions which relate to a small hydro development operating as a public utility. Simplistically, the operation is regulated as a public utility if the power is to be sold to the proposed users. Several alternatives are available to organize and operate as a public utility depending on the size of operation, the users of the power, and the nature of the owner/operator of the proposed utility. This chapter outlines these alternatives, the conditions required for each alternative and the implications to both the owner/ operator and the user for each alternative.

10.2 RATIONALE FOR UTILITY REGULATION

The rationale for regulating a small hydro facility as a public utility is to provide protection and security for both the shareholders of the utility and the customers paying for the electric utility service. This ensures that the utility is publicly accountable and creates an avenue to receive and mediate complaints from both the utility and its customers.

The B.C. Utilities Commission acts as the regulatory body for public utilities regulated under the Utilities Commission Act. For municipal utilities, municipal councils would initially arbitrate complaints, with final arbitration and accountability made to the Ministry of Municipal Affairs.

10.3 RELEVANT LEGISLATION

B.C. Utilities Commission Act

The B.C. Utilities Commission Act SBC, 1980, c.60 provides for the regulation of public utilities and establishs the B.C. Utilities Commission as the body responsible for the regulation of public utilities.

The Utilities Commission Act defines a public utility as anyone who owns or operates equipment or facilities for the production, generation, storage, transmission, sale, delivery or furnishing of electricity for the production of light, heat, cold or power to or for the public or a corporation for compensation within the Province of British Columbia. A person who furnishes the service or commodity only to himself, his employees or tenants, so that the service or commodity is not resold to or used by others, is not a utility.

A public utility as defined under the Utilities Commission Act, does not include a municipality or regional district in respect of services furnished by the municipality or regional district within its own boundaries.

Part 3, Regulation of Public Utilities, of the Act applies to those small hydro developers who intend to operate as a public utility. It is emphasized that the provisions and conditions set out in Part 3 are directed for the most part to large public utility companies.

Section 27 of Part 3 of the Act outlines the regulatory conditions for a person generating electricity for his own use and for the sale of any surplus power.

Part 2 of the Act outlines the requirements by which regulated projects are reviewed and certified. Regulated projects are defined according to the amount of energy used or involved in production or transmission. For the purposes of this manual, small hydro would not be considered a regulated project and thus Part 2 of the Act does not apply. Regulated projects would be hydro power plants of 20 MW or higher. Developers of hydro electric energy projects of 20 MW or more should refer to "Guide to the Energy Review Process", 1982 published by Ministry of Energy Mines and Petroleum Resources.

B.C. Municipal Act

Under the Municipal Act, RSBC, 1979, c.290, a municipal utility may provide for the establishment and use within or without the municipality of plants to supply electrical energy and an electrical energy distribution system for the purpose of the inhabitants of the municipality or for the inhabitants of the municipality and adjacent localities (refer to Part 14, Division 2 of the Municipal Act).

10.4 REGULATORY ALTERNATIVES

A small hydro development will be regulated in one of four basic ways depending upon the user of the power, the size of the operation and the nature of the owner/operator. The four basic operating situations are:

(a) generating electricity totally for own use, including use by employees and tenants;

(b) generating electricity primarily for own use, with provision to sell surplus power;

(c) local government (e.g. incorporated municipality) generating electricity for public use;

(d) Anyone other than a local government generating electricity for public use.

At the point in the conception of a small hydro development when application for a water licence is being made, contact should also be made with the Minister of Energy Mines and Petroleum Resources, the B.C. Utilities Commission or the Minister of Municipal Affairs depending on the projected use of the power (see figure 1).

REGULATORY ALTERNATIVES FOR SMALL HYDRO PROJECTS

(less than 20 MW)

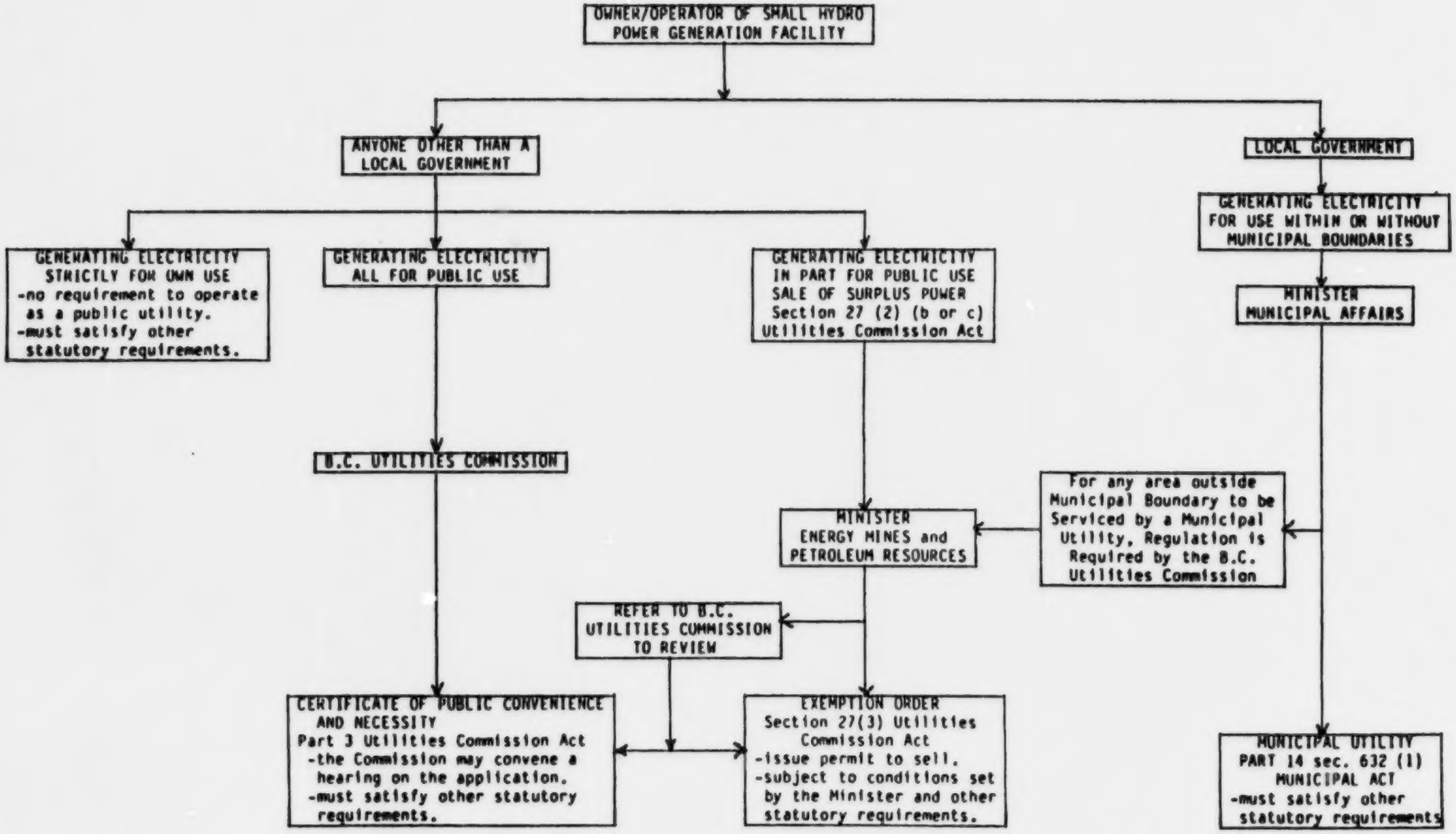

OWNER/OPERATOR OF SMALL HYDRO POWER GENERATION FACILITY
ANYONE OTHER THAN A LOCAL GOVERNMENT
LOCAL GOVERNMENT
GENERATING ELECTRICITY STRICTLY FOR OWN USE -no requirement to operate as a public utility. -must satisfy other statutory requirements.
GENERATING ELECTRICITY ALL FOR PUBLIC USE
GENERATING ELECTRICITY IN PART FOR PUBLIC USE SALE OF SURPLUS POWER Section 27 (2) (b or c) Utilities Commission Act
GENERATING ELECTRICITY FOR USE WITHIN OR WITHOUT MUNICIPAL BOUNDARIES
MINISTER MUNICIPAL AFFAIRS
B.C. UTILITIES COMMISSION
For any area outside Municipal Boundary to be Serviced by a Municipal Utility, Regulation is Required by the B.C. Utilities Commission
MINISTER ENERGY MINES and PETROLEUM RESOURCES
REFER TO B.C. UTILITIES COMMISSION TO REVIEW
CERTIFICATE OF PUBLIC CONVENIENCE AND NECESSITY Part 3 Utilities Commission Act -the Commission may convene a hearing on the application. -must satisfy other statutory requirements.
EXEMPTION ORDER Section 27(3) Utilities Commission Act -issue permit to sell. -subject to conditions set by the Minister and other statutory requirements.
MUNICIPAL UTILITY PART 14 sec. 632 (1) MUNICIPAL ACT -must satisfy other statutory requirements

FIGURE 1

Discussion with the pertinent Ministry about the specifics of the project will help direct the route a particular project should take regarding its regulation as a public utility. Figure 1 shows the general routes that would be followed for the four basic operating situations presented above. Either the Ministers of Energy Mines and Petroleum Resources, or Municipal Affairs, or the B.C. Utilities Commission will be able to assess the specifics of each individual project with respect to its operation as a public utility, and advise the proponent on the specific type of certification and application requirements needed.

The following provides the broad criteria which will determine how (or if) a small hydro development will be regulated.

Scale of project

Greater than 20 MW: beyond the scope of small hydro as defined in this manual; designated as a regulated project to be certified under the Utilities Commission Act.

Less than 20 MW: will be regulated as a public utility depending on the use of the power.

Use of Power

Generating electricity totally for own use including employees and tenants: has no requirement to operate as a public utility regulated by the Utilities Commission.

Generating electricity primarily for own use with surplus power which could be sold to other users: requires a review by the Minister of Energy Mines and Petroleum Resources who may approve the sale of surplus power or may determine that the sale of surplus power should be regulated by the Utilities Commission.

Generating electricity for public use: involves the sale of power to the public and is therefore a public utility; the type of public utility depends on the owner/operator of the small hydro facility.

Owner/operator of Small Hydro Development for Public Use

Local government (incorporated municipality) owns and operates small hydro development for public use: requires the formation of a municipal utility as defined in the Municipal Act.

Anyone other than a local government owns and operates small hydro development for public use: is a public utility regulated by the Utilities Commission.

10.5 APPLICATION PROCEDURES

In all instances a water licence is required for a small hydro development. As water licence approvals can take from 6 to 12 months for approval (refer to Chapter 6), applications should be made as early as possible in the planning process.

You should consult the pertinent Ministry and/or the B.C. Utilities Commision prior to entering the application process. This initial contact will identify:

(a) the person to whom the application should be directed and the type of certification required (e.g. Certificate of Public Convenience and Necessity),

(b) the specific requirements necessary for an application, for example, extent of background information on the project, type of documentation to establish financial and technical capacity, and ancillary applications,

(c) the additional information that is needed so that advice and response from government agencies can be obtained before a formal application is made.

The application requirements for small hydro developments operating as public utilities are not well defined. This reinforces the need for ongoing consultation with the pertinent government agencies. Four general operating situations for small hydro developments are presented in Section 10.3. Three of these situations involve operating as public utilities. Each situation may encompass a broad range of projects. Public utilities regulated by the Utilities Commission may range from an investor owned utility providing power to 20 people to a larger municipal utility, providing power to 11,000 users within a municipality and to an area adjacent to the municipal boundaries.

The following provides an overview of the application procedures and requirements for the three situations which involve operation as a public utility. The procedures and requirements are necessarily general as much is left to the discretion of the Minister and the Utilities Commission depending on the specifics of individual cases.

10.5.1 Investor or Cooperative Owned Public Utility

An investor or cooperatively owned public utility which is generating power for public use is subject to Part 3 of the Utilities Commission Act. Thus the utility is subject to regulation by the Utilities Commission and requires a Certificate of Public Convenience and Necessity to construct, maintain and operate a small hydro development (Section 51 Utilities Commission Act).

An application for a Certificate of Public Convenience and Necessity is made to the B.C. Utilities Commission. The application requirements are prescribed by the Commission, Sec. 53(1). In general terms the application should include:

Description of the Applicant

The name, address and nature of business of the applicant should be stated. This should include all other persons having a direct interest in the ownership or management of the project. The name, title and address of the person with whom to communicate should also be noted.

Evidence of the applicant's financial and technical capacity, and that of anyone else involved in the project should be given. An example of such financial documentation would be a certified copy of the memorandum and articles of association of the applicant.

Project Description

There should be a description of the project, its purpose and cost, including all ancillary or related facilities that will be constructed, owned or operated by the applicant.

An outline of the anticipated time table for construction, operation and abandonment should be made together with dates by which critical events must take place to ensure continued economic viability. As applicable, identify any potential impacts by the project on the physical, biological and social environments. Outline proposals for reducing negative impacts and maximizing benefits from positive impacts.

Project Justification

The technical, economic and financial feasibility of the project should be outlined. This should include a proforma containing proposed terms and conditions of service and proposed rate schedules. The project justification should include projections or schedules giving estimates of:

(a) plant in service: estimate of costs for generation, transmission, and distribution,

(b) income and expenses: profit and loss projections for a period normally more than one year,

(c) schedules for rate of return from capital employed.

Ancillary Applications

Identify if a water licence under the Water Act has been obtained, or if and when an application was made. Other approvals, permits or licences required under federal, provincial and municipal law should also be listed (refer to Chapter 5).

Other

Depending on the size and nature of the project, a description of the applicants public involvement program should be included.

Depending on the nature of the project, the Commission may convene a hearing on the application for a Certificate of Public Convenience and Necessity.

A public utility which has been issued a Certificate of Public Convenience and Necessity may construct, maintain and operate a small hydro plant or system as authorized in the Certificate (Section 53(7) Utilities Commission Act). If approved, the public utility must satisfy other statutory requirements (refer to Chapter 5).

10.5.2 Sale of Surplus Power

Anyone can generate electricity strictly for his own use, which includes employees and tenants, without being regulated as a public utility by the Utilities Commission. However, if a person wishes to sell any part of the power service that is surplus to his requirements, he is required to make application to the Minister of Energy Mines and Petroleum Resources.

The Minister may on his own, or after review by the Utilities Commission, issue a permit to sell under an Exemption Order (section 27 (3) Utilities Commission Act). The Order would be subject to terms and conditions set by the Minister respecting the extent or quantity of power service to be sold, the price to be charged for the power service and other conditions that the Minister or the Commission considers to be in the public interest.

The Minister may refer the application to the Utilities Commission if: the quantity of surplus power to sell is great enough; or there is competition between customers for the service; or there is an overlap with service from another utility.

The application requirements for an Order permitting the sale of surplus power would be whatever information, material, evidence and documents that the Minister or Commission prescribes. Contact should be made with the Ministry prior to formal application to determine the specific information required for an application. The following provides an outline of the type of basic information which may be required:

Description of the applicant

A description of the applicant should include the name, address and nature of the applicant's business. Evidence should also be provided of the financial and technical capacity of the applicant.

Description of Project

A description of the project should be given together with a description of any new facilities or expansions that are planned.

Justification for Sale of Surplus Power

Justification for sale of surplus power may include a proforma or sales contract containing proposed terms and conditions of services and proposed rate schedules. Income and expenses should be estimated (eg. profit and loss projections for more than one year).

10.5.3 Municipal Utility

A utility which is owned and operated by a local government, such as an incorporated municipality, does not fall under the Utilities Commission Act and is therefore regulated under provisions contained in Part 14 (Division 2) of the Municipal Act.

A municipal utility may provide electrical power to users within a municipal boundary and to surrounding localities. Service within municipal boundaries is subject to regulation by bylaw and approval of the Minister of Municipal Affairs. Service outside municipal boundaries is subject to regulation by the Utilities Commission.

The procedure to become a municipal utility as described in Section 632 of the Municipal Act includes:

(a) a bylaw passed by Council to create a municipal utility. The bylaw would include a set of conditions and attached rate schedule;

(b) assent of the electors through means such as a petition or a public referendum;

(c) approval of the Minister of Municipal Affairs. Approval may be subject to conditions set by the Minister and other statutory requirements.

10.6 ORGANIZATIONAL STRUCTURE AND ACCOUNTING PROCEDURES

10.6.1 Organizational Structures

Investor Owner Utility

An investor owned utility organization is typically a private or publicly owned company with a Board of Directors, Chairman, President, Manager, and Administration and Operation Divisions. Figure 2 is an organization chart for an investor owned small hydro utility. In a small utility, one person may serve in one or more positions.

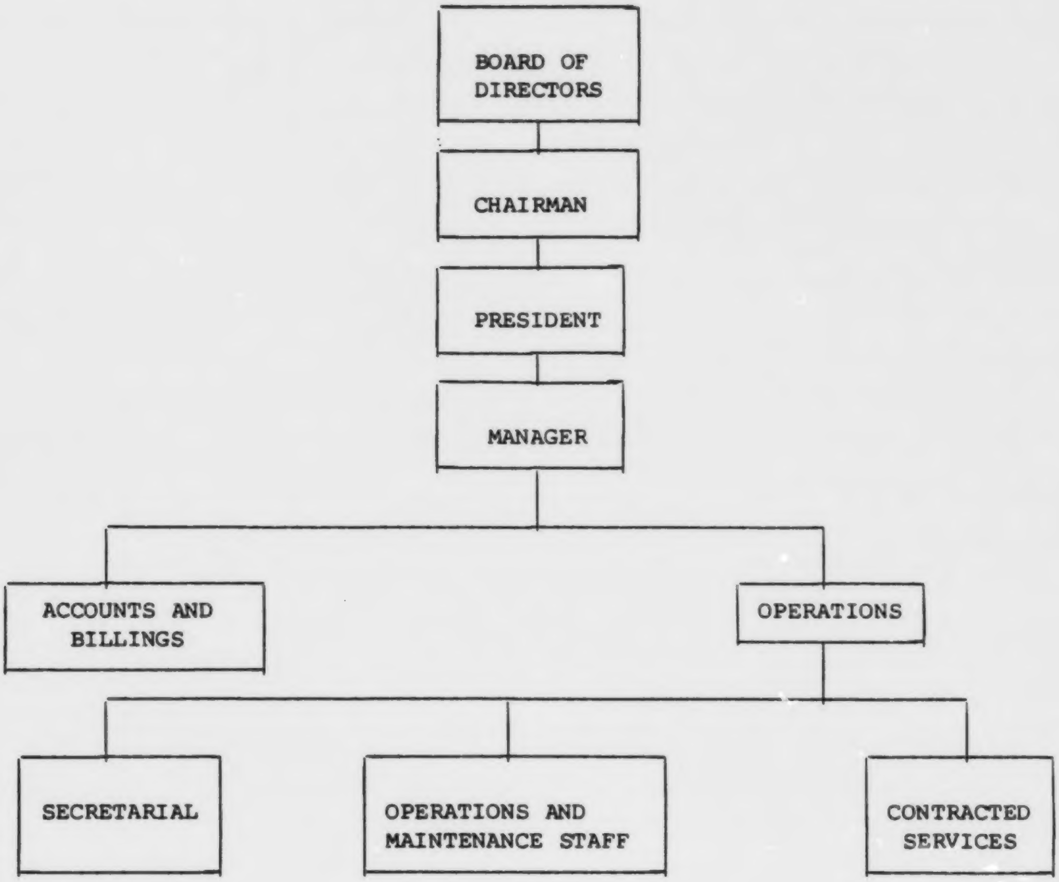

BOARD OF DIRECTORS
CHAIRMAN
PRESIDENT
MANAGER
ACCOUNTS AND BILLINGS
OPERATIONS
SECRETARIAL
OPERATIONS AND MAINTENANCE STAFF
CONTRACTED SERVICES

FIGURE 2

Municipal Utility

A typical local government organization is subject to the provisions of the Municipal Act. Such an organization is guided by the policies established by a local Council or some other elected or appointed body, and is administered by a local government Administrator or Utility Manager. Figure 3 is an organization chart for a municipally owned small hydro utility.

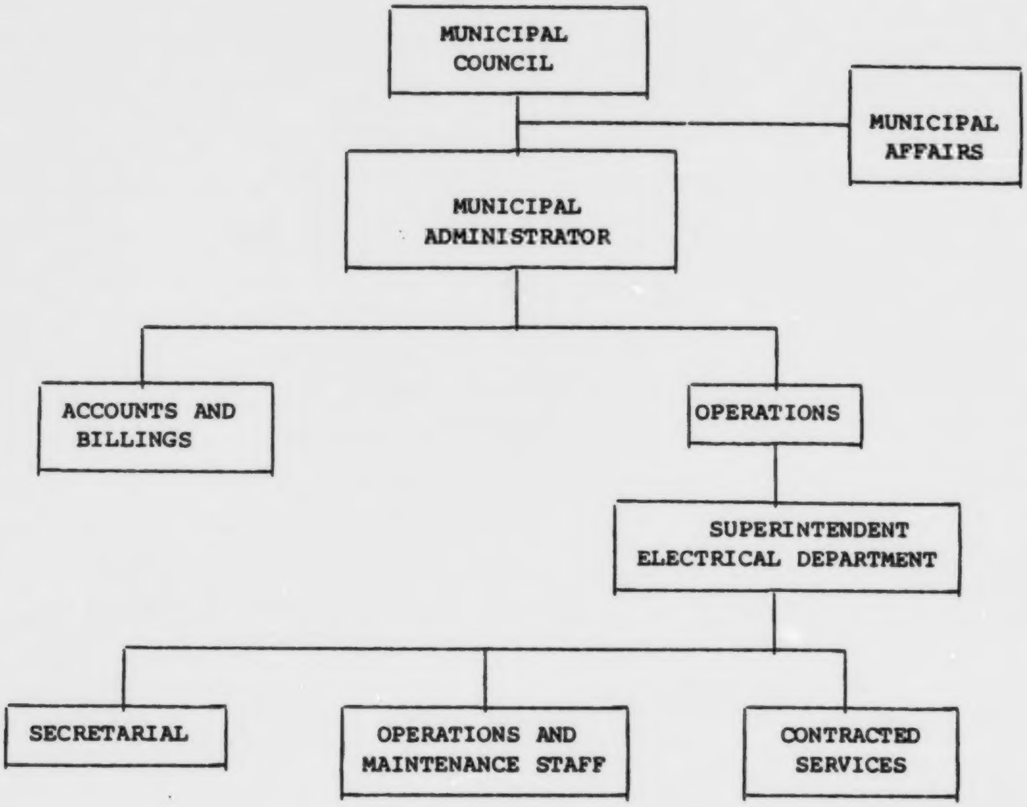

MUNICIPAL COUNCIL
MUNICIPAL AFFAIRS
MUNICIPAL ADMINISTRATOR
ACCOUNTS AND BILLINGS
OPERATIONS
SUPERINTENDENT ELECTRICAL DEPARTMENT
SECRETARIAL
OPERATIONS AND MAINTENANCE STAFF
CONTRACTED SERVICES

FIGURE 3

10.6.2 Accounting System

Public utilities in Canada and the United States usually adopt a Uniform System of Accounts. The details of the System vary in complexity, depending on the size of the public utility. Large or small, the System adopts a Chart of Accounts, usually under four separate headings:

Balance Sheet Accounts
Electric Plant Accounts
Income Accounts
Operation and Maintenance Expense Accounts

There is an elaborate numbering system to identify accounts in a uniform manner. The small hydro utility should use this system as a base and, in conjunction with the specified need of the Utilities Commision, select those specific accounts that are pertinent. (Refer to Section 56, Utilities Commission Act).

There are nine series of accounts, as follows:

Balance Sheet Accounts: 100 Series - Assets
200 Series - Liabilities

Electric Plant Accounts: 300 Series - Generation, Transmission and Distribution

Income Accounts: 400 Series - Revenue, Expenses, other Income & Deductions

Operation and Maintenance: Expense Accounts: 500 Series to 900 Series Various Operation and Maintenance Accounts

10.6.3 Capital and Operating Budgets

Capital project budgets are prepared annually and list anticipated expenditures and expected funding sources. A small hydro utility of the 250 kW generating capacity class may have a capital budget similar to the following example.

1985 Capital Project Budget

Description	Capital Cost	Funding Source
Electrical Service		
New Machinery and Equipment Purchases (Tools, vehicles, switchgear, pole lines, transformers, etc.	$ 20,000	Bank Loan
Replacement Machinery and Equipment Purchases.	10,000	Revenue from Energy Sales
Street Lights		
Street lighting for new areas.	5,000	Direct charges to Community
Replacement of old street lighting.	2,000	(i.e. from Municipal Revenue)

Power Generation & Transmission

New Equipment	--
Replacement Equipment	5,000
TOTAL 1985 Capital Project Budget	$ 42,000

Operating budgets are prepared annually and list anticipated revenues and expenditures. A small hydro utility of the 250 kW generating capacity class may have an operating budget similar to the following example.

1985 Operating Budget

Item	1984 Actual	1985 Estimated	Increase or Decrease	% Increase or Decrease
Revenue				
Energy Sales:				
Residential	$ 70,000	$ 75,000	$ 5,000	7%
Commercial	20,000	21,000	1,000	5%
Institutional (Schools, hospitals, etc.)	10,000	11,000	1,000	10%
Municipal (Municipal offices, library, water pumping, etc.)	10,000	11,000	1,000	10%
Total Energy Sales	$110,000	$118,000	$ 8,000	7.3%
Street Lighting	5,000	6,000	1,000	20%
Connection Fees	500	600	100	20%
Service Charges	1,500	2,000	500	33%
Other Revenue	500	500	--	-
TOTAL 1985 REVENUE	$117,500	$127,100	$ 9,600	8.2%

Item	1984 Actual	1985 Estimate	Increase or Decrease	% Increase or Decrease
Expenditures				
General:				
Salaries and Wages	70,000	72,000	2,000	3%
Equipment Rentals (Cars, trucks, etc.)	5,000	5,000	-	-
Communication (telephone, radio)	600	600	-	-
Professional Fees	2,000	2,000	-	-
Insurance	4,000	4,000	-	-
Local Taxes	-	-	-	-
Office Rental	5,000	5,000	-	-
Office Equipment and Supplies	4,000	4,000	-	-
Capital Projects:				
Electrical Services	1,000	1,500	500	50%
Street Lights	400	500	100	25%
Power Generation and Transmission	600	700	100	17%
Purchased Services & Rentals:				
Repair Services	3,000	3,000	-	-
Equipment Rentals	2,000	2,200	200	10%
Other Items:				
Repair Parts	1,000	1,000	-	-
Building Maintenance	500	500	-	-
TOTAL 1985 EXPENDITURES	$99,100	$102,000	$2,900	2.9%

10.6.4 Accounting Procedures

A small hydro utility following a uniform system of accounts would have debit balance accounts listing assets and expenses, and credit balance accounts listing liabilities, equities and revenue. The following list would be typical.

Accounts with A Debit Balance:

Assets:

Bank Account (Cash)
Accounts Receivable
Short Term Investments (Bank, etc.)
Materials and Supplies Account
Generator Plant Account

Transmission Facilities Account
Distribution Facilities Account

Less Accumulated Depreciation and Amortization Account

Expenses:

General Account
Capital Projects Account
Purchased Services and Rentals Account
Add Depreciation Expense Account

Accounts With A Credit Balance:

Liabilities And Equities:

Accounts Payable
Notes Payable Account (Loans by corporations or government)
Long Term Debt Account (Municipal bonds, etc.)
Bank Loans (for capital projects or for operating capital)

Revenue:

Energy Sales
Other Revenue

10.6.5 Reporting Procedures

Reporting procedures will vary depending on the nature and size of the public utility. Those applicable to a small hydro utility of the 250 kW generating capacity class include the following:

A Public Utility Operated By A Local Government:

Annual Budgets for Council Approval
Capital Projects Budget
Operating Budget
Summary of Sales and Revenue for B.C. Utilities Commission (if required)

A Public Utility Not Operated By A Local Government:

Annual Budgets for Directors and/or Management
Summary of Sales and Revenues for B.C. Utilities Commission (if required)
Reporting Under The Companies Act
Report to the Shareholders

10.7 IMPLICATIONS TO ORGANIZING AND OPERATING AS A PUBLIC UTILITY

A utility is regulated to provide protection and security for both the utility owners and its customers. Prior to making a commitment to becoming a public utility, a careful consideration should be made with respect to the continuity of service and the limitations as to the availability of the service. A public utility must remain in operation until either the Utilities Commission or a Municipal Council gives permission to discontinue the service.

10.7.1 Commitment to the Public

A small hydro project which is intending to supply power for public use must state the limitations to the service in its application to the appropriate Ministry (see section 10.5). Examples of limitations to consider may include:

(a) limitations as to the area to be served, that is, the service area boundaries which may, or may not, include an entire community;

(b) limitations as to the schedule or time frame for servicing all or parts of the service area. Street lights, for example, may not be planned for outlying areas.

The capacity and characteristics of any given service may be limited by the capability of the system and the policy of the utility. For example, a user with a potentially high connected load, or one which may cause wide or abnormal fluctuations, may need to be restricted, otherwise the quality of service to other users may suffer.

10.7.2 Operation, Safety and Reliability of Service

In the case of a public utility owned by a local government, the regulation, inspection, control, use of and rates are set out in an Electricity Regulation By-Law. Public utilities not owned by a local government would provide service to its customers utilizing an electrical service contract.

A public utility must be able to respond to trouble calls with reasonable dispatch. The by-law or service contract, however, should clearly state the limit of liability that the public utility assumes in case the supply of electricity fails. The utility needs to be so protected against claims for damage caused by such failure.

A public utility must provide equipment and plant and must carry out its activities in keeping with applicable standards and codes. (Also see Chapter 5). Included among these are:

(a) Canadian Electrical Code for equipment, installation and operation;
(b) Worker's Compensation Act for safety of workers and safety of the work place;
(c) Factories Act (Provincial) for requirements of equipment installation and plant;
(d) Electrical Energy Inspection Act (Provincial) for the requirements of inspection of installations;
(e) Electrical Inspection Act (Federal)

No service shall be provided to a potential customer whose electrical installation has not been given an electrical inspection certificate by a bona fide electrical inspector.

SMALL HYDRO POWER HANDBOOK

GLOSSARY

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A. CASE STUDY EXAMPLES

A.1 KINGCOME INLET HYDRO POWER PROJECT

A.1.1 Background

The Kingcome Inlet Hydro Power Project is located near the Gwa-yee village of the Tsawataineuk Band, about 100 km east of Port Hardy. The area was first studied in 1978, when an investment report was carried out to evaluate the hydro power potential of three nearby creeks. At the same time, a comparison was made with the cost of providing full diesel power to the village. The study made a recommendation to develop the creek on the opposite side of the river from the village with a plant size of 75 kW to serve the 20 homes, and 5 community buildings. It was anticipated that the village population would grow once a reliable source of power became available.

A.1.2 Design

The first stage in the design was to determine the hydrology of the selected basin. This was made difficult by the lack of local available streamflow data, which is a common problem in the analysis of small hydro power resources. However the data for the creek was estimated, using the local rainfall records and streamflow data from other creeks in a similar coastal precipitation zone; The nearest creek is about 100 km away. The stream was estimated to have a power availability requiring supplemental diesel generation about 15 percent of the time for 75 kW.

The layout of the project was the next stage. The creek flowed out of a hanging valley on to an alluvial fan just above the level of the Kingcome River. The first suitable intake site was located about 170 m above the powerhouse site (at the head of the alluvial fan). In between the intake and powerhouse the creek flowed over a series of waterfalls within an inaccessible canyon. The penstock was routed between the canyon rim and a logging road, which provided access to most of the penstock route. The penstock was mainly located in a narrow clearing and much of the installation work was done by hand to minimize disturbance of the soil and vegetation on the steep cross slope.

The main design feature of the penstock was its construction in polyethylene and the use of pipe bridges for creek crossings. Polyethylene pipe was advantageous because it could be easily bent around the many obstacles encountered and could be moved into place by hand. The pipe was secured to the ground using saddle clamps bolted to rock or pedestals. As the pipe went down the hill, the rating was increased to match the pressure increase. Once the pressures became too great for polyethylene, the pipe type was changed to welded steel for the remainder of the pipe down to the powerhouse. Pipe bridges were used to carry the pipe over creeks and canyons spanning up to 30 metres. Using steel hollow structural sections, lengths of the polyethylene penstock were threaded through and continuously fused together.

The powerhouse was designed around the turbine, generator and governor unit. Sufficient space was provided for servicing components and a powerhouse crane was provided, due to the relative inaccessibility of the site and the lack of servicing equipment owned by the plant operator. A steel frame building was selected, both to speed on-site erection and to support the crane loads. Power is transmitted to the village along a single phase pole line 1 km long, featuring a 150 m crossing of the Kingcome River, which ties into a village distribution system.

Provision for expansion of the project was made by increasing the penstock one size to 250 mm diameter and by installing a bifurcation just upstream of the powerhouse. This allows for another 75 kW of power to be developed with the addition of a short length of steel pipe, another powerhouse and another turbine generator unit. The possibility exists to supply power to the nearby logging camp, or increase power supply to the village when needed.

A.1.3 Contracts

The Kingcome Project was built in several stages. The first contract was for the equipment package, including a turbine, governor, generator and control panel. This equipment arrived well in advance of the construction phase and the responsibility for shipping to the site and storage was included in the work of the general contractor.

Public tenders were called for construction of the intake, penstock, powerhouse transmission line and equipment installation. The low bidder was a general contractor, who had a major subcontract with an electrical contractor experienced in small hydro. Full time engineering supervision was provided to assist in developing the layout, interpreting drawings and maintaining construction records. Commissioning was assisted by a representative of the turbine supplier.

A.1.4 Construction

Construction on the project began in September 1981. About two-and-a-half months was required to complete the clearing, intake, most of the penstock, powerhouse and part of the transmission line. After a mid-winter break, a further one-and-a-half months was required to complete and commission the project.

The major problems encountered in construction related to the weather. Fall rainstorms resulted in difficulties with the instream work at the intake and slowed the pace of work when concrete and piping segments were being done. However, the contractor was well prepared, and provided shelter over the welding operations and heat for winter concrete pours. Despite 30 cm to 60 cm of snow through much of the winter, the work was not affected severely, because the higher level work was completed before the snow fell, and snow falls at lower levels were considerably less. Materials handling was also a problem, with one of the extra long poles being broken in shipping and its replacement also broken by mishandling by someone not employed by the contractor. The cost of the broken pole was far exceeded by the cost in time required to secure a replacement pole and redeploy a crew.

A.1.5 Operations Experience

The plant was commissioned in March 1982 and operation was taken over by a local resident. The operation was supported by an Operation and Maintenance Manual, provided by the project designer and by manuals from the turbine, generator and governor manufacturers. The first problem to arise was a penstock break in the polyethylene pipe. This was later found to be caused by improper fusion during construction, and the problem was repaired under warranty by the contractor.

Other problems were centered around the turbine and governing system. The governor drive motor has failed twice, and although it is relatively easy to replace, (given the availability of a spare unit) the plant is shut down during this time. The failure of the motor also leads to unpredictable operating conditions, and points out the need for having an effective protection and monitoring system. Such a system was installed at Kingcome shortly after commissioning, and the system now also protects other components.

Still another major problem concerns the turbine wear characteristics. The nature of the crossflow design causes some unusual flow patterns and these combined with sediment entering the system has resulted in wear on the control valve, runner and housing. The turbine was pulled from service and rebuilt after about two years of operation, and a sediment removal device was installed on the penstock. It is too early to tell the effect of these measures and whether any other problems remain with the turbine, or with maintenance procedures involving sediment cleanout at the intake.

A.1.6 Project Summary

Kingcome Hydro Power Project

Capacity:	150 kW (75 kW installed)
Gross Head:	170 m
Penstock Length:	693 m
Penstock Diameter:	250 mm
Intake:	Concrete side channel box with coarse trash racks, fine trash screens, bellmouth inlet, shutoff valve and air vent

Powerhouse:	Steel frame with two ton overhead crane, concrete slab
Turbine:	75 kW Ossberger Crossflow
Generator:	75 kW Kato Single Phase 120/240 Volt, 1200 RPM
Governor:	Woodward UG8 with Size 1 Hydraulic Pumping Unit
Transmission Line:	2400 volt; single phase #2 ACSR wire on Class 2 Poles; 1000 m long.

A.1.7 Construction Cost Summary

Preliminary Engineering Studies and Site Investigation		$ 20,000
Design		35,500
Tendering and Contract Management		7,200
Full Time Engineering Supervision, Inspection, Contract Administration and Project Management		93,500
Construction		
Clearing	$ 34,500	
Intake	50,300	
Penstock	245,600	
Powerhouse and Electrical	90,650	
Powerline (1 km)	37,100	
Installation and Commissioning	11,100	
Extra Work	23,655	492,900
Generation Equipment		73,400
Protection and Monitoring System		23,300
		$ 745,800

A.2 MOSES INLET HYDRO POWER PROJECT

A.2.1 Background

The Moses Hydro Power Project had been under consideration for several years, beginning in 1982 when a private contractor initially approached Crown Forest Industries Ltd. with the idea of developing the hydro power resource to serve its forestry camp located near Ebert's Cove on Moses Inlet, about 125 km North of Port Hardy. Subsequently the site was recorded in the Remote Community Demonstration Program's Overview Study for British Columbia, sponsored by Energy, Mines and Resources Canada.

The Remote Community Demonstration program also sponsored a study on the feasibility of a private investor developing the hydro power resource at Moses Inlet. This study looked at both the technical and economic aspects of the development, and has formed the basis of subsequent work. The study concentrated on developing the optimum size of project considering the variables of hydrology and demand.

Shortly after the feasibility study was completed in March 1984, a Lease Contract proposal was made to Crown Forest. The contract essentially involved construction of the project for Crown Forest, then graduated quarterly lease payments by Crown for 10 years. After the application of a buyout clause the ownership of the hydro power plant would revert entirely to Crown Forest.

While details of the contract were being discussed, some preliminary work on the project was authorized by Crown Forest in order to expedite the construction once all approvals were obtained. Preliminary work included applying for land use permits and water licences, and obtaining quotations from turbine suppliers.

A.2.2 Design

The design of the Moses Project was relatively straightforward, and was dictated by the optimization criteria. The preliminary design used in the feasibility study was based on coarse mapping and one field inspection conducted in poor weather. However, the few variables in routing allowed the forest company to extend the existing access road to the vicinity of the intake. This allowed the location of the intake to be optimized relative to the expected costs of the penstock and the powerhouse, and resulting power output. Power output was a function of both the head and the location, as lower heads also had greater flows.

Once the locations were optimized, the design task involved material selection, sizing and final location. Most of the penstock could be built as buried PVC water pipe, which is usually the least expensive pipe system. The upper reaches of the penstock presented a more typical problem: Water had to be carried from the intake on a downward slope as well as remain clear of the creek, however road access was on the left bank, while the predominant part of the upper penstock and the intake were on the right bank. The constraints dictated that polyethylene pipe supported by rock saddles and wood trestles would be used. Hand placement in rough terrain was convenient and the coupler joining system avoided the use of fusion which needs high quality control standards not easily attainable on the site. Once clear of the area only accessible on foot, the polyethylene pipe was maintained over a length of rough and unstable ground prior to converging to PVC.

The intake design criteria consisted of flow maintenance, ice-free operation, and sediment separation. These factors were achieved while minimizing creek disturbance by using a large diameter culvert section, with a bottom sediment outlet and trash screen. The culvert was placed in a shallow excavation at the side of the stream channel, then backfilled to restore the intake pond.

The powerhouse design was dictated by several local concerns. The forest company required a new powerhouse for its existing diesel generators so these were to be incorporated under one roof, for convenient synchronizing with the hydro turbine. Special isolated inertia blocks were used to dampen vibrations from the diesels. The building was wood frame, without a crane, because the location was accessible.

The station electrical design is the most important aspect of the system, because it is responsible for maintaining an optimum delivery of hydro power. The camp potential load far exceeds the capacity of the hydro turbine, but by managing the load to reduce peaks and using the diesels for load peaks that do occur, the efficient delivery and use of a maximum amount of hydro power can be achieved. When the loads approach the hydro plant capacity, the diesel will start up and synchronize automatically. Then as the load increases, the diesel will take up the amount of load which exceeds the hydro plant capacity, and as soon as loads are below the hydro plant capacity, the diesel will shut down. Control of the turbine operating below its capacity is obtained with a jet deflector and with a manual needle valve to reduce flows in the event of low streamflow.

A.2.3 Contracting

Construction

The Moses Project was contracted in several stages, and involved the assistance of the forest company for the provision of site services (accommodation, equipment, fuel) as well as the site preparation. The intake, penstock and powerhouse contract was awarded first, followed by the turbine/generator contract. The electrical installation contract followed later, as it was dependent on input of design information from the turbine supplier and was not needed until just prior to the turbine installation.

Leasing

The above contracts were governed by a master agreement between the project owner and the forest company. The master agreement covered terms of payment, timing, guarantees and maintenance and was the basis by which the work could proceed. The agreement provided for a schedule of lease payments to be made to the owner at the beginning of power availability. Such agreement was also necessary in order to secure third party financing of the project.

A.2.4 Construction

Construction work was initiated in November 1984 with the intake, penstock and powerhouse contract. Aside from the usual weather problems, no major problem was encountered until January when the backhoe was damaged digging the penstock trench in frozen ground. It was then realized that the machine was too light for the task. Work was delayed until the forest company's large backhoe was available, and the contract was completed in mid-March 1985. A total elapsed time of about 45 days was needed for the work. The delays did not cause any disruption in the overall schedule, as the turbine contract was not scheduled to finish until later.

Toward the end of construction, the forest company connected a domestic water system to the penstock, to serve the camp through a pressure reducing valve. In addition, several standpipes for fire protection were installed on the same line.

The electrical installation began in May 1985, while the turbine was installed in July 1985.

Full time supervision was provided for the civil works portion but only final inspection and commissioning/testing inspection were provided for the electrical and turbine installation.

A.2.5 Operating Experience

Part of the lease contract called for the production of an Operation and Maintenance Manual for the use of the camp personnel who handle the day to day system operations. Provision for detailed record keeping on both maintenance and power production was made. Provision of specialized maintenance and nonroutine repairs is to be made by the project owner.

The powerplant has been operated successfully up to an output of 85 kW, but a number of operating problems have occured. These include: a penstock break related to a faulty fitting; frequent stops and starts and low load running on the diesels; lack of operator confidence due to frequent rotation of camp personnel and inexperience with the system; two summers of record low rainfalls leading to low summer output; miscellaneous mechanical and electrical problems with the diesels and the synchronizing system.

Most of these problems have been solved in a few days of occurrence. Some have been the responsibility of the camp owner and some the responsibility of the small hydro project owner. The most difficult problems have been related to the operator confidence and the energy management system. The confidence problem often resulted in the plant being shut off while caretakers looked after the camp during a crew furlough and ran the diesel alone. The energy management system was installed at the camp's direction, and while it was relatively easy to install it did not lead to the proper result, being connected to isolated high, short duration loads instead of low capacity long duration loads. The effect was that the energy management system as initially installed was a cause of the diesel start/stop problems, indirectly a cause of some of the operator lack of confidence and consequently lower than expected plant performance resulted. Continued monitoring will confirm the effect of these measures. In addition a conversion of the manual flow control valve into an automatic slow acting valve to track water flow changes is being planned to further improve operation.

A.2.6 Project Summary

Moses Hydro Power Project

Capacity:	75 kW
Gross Head:	95 m
Penstock:	
Length	750 m
Sizes	250 m of 250 mm diameter polyethylene Series 60 250 m of 300 mm diameter PVC Series 100 250 m of 250 mm diameter PVC Series 160
Intake:	Corrugated steel side channel culvert with coarse trash racks, sediment outlet, shutoff valves and air vent.
Powerhouse:	6 x 9 m wood frame, steel clad with concrete slab, houses 1-60 kW and 1-100 kW diesel generation sets and 1 - 75 kW hydro turbine/generator. Roof design for 90 psf ground snow load.
Turbine:	75 kW Dependable Turgo Impulse Wheel, 375 mm.
Generator:	75 kW Kato 3 phase 120/208V, 900 RPM (to match diesel generator voltage).
Governor:	Thomson and Howe Product G(electronic) with hydraulic jet deflector. Manual needle valve.
Transmission Line:	600 Volt 3 phase pole line, 150 m long. Step up and step down transformers.

A.2.7 Construction Cost Summary

Preliminary Engineering Studies (The nature of the project required more analysis of options than would normally be required, leading to significantly higher cost at this stage)			$ 20,000
Design, Tendering, Supervision and Contract Management			47,500
Construction			
Intake		$ 14,000	
Penstock		62,500	
Powerhouse (including space for diesels)		39,000	
Turbine Generator (Supply and Install)		87,500	
Electrical Installation	(Est.)	45,000	
Site Services by Forest Company	(Est.)	10,000	
Extra Work		3,000	
Installation/Commissioning		2,000	
Protection and Monitoring		INCL.	
Domestic Water and Fire Protection		2,000	265,000
TOTAL:			$332,500

The project was constructed in 1982 under the Federal Provincial Conservation and Renewable Energy Demonstration Agreement (the predecessor to the Remote Community Demonstration Program) with a contribution from the government of 16 percent toward the construction cost. The additional $5,000 cost of monitoring and information transfer was paid exclusively by CREDA.

A.3 NIMMO BAY RESORT HYDRO POWER PROJECT

A.3.2 Design

The project was sized at 35 kW to serve most of the energy needs of the resort. The design of the project is not documented, but it is presumed that the turbine supplier provided much of the system design including electrical, along with advice on the penstock and intake.

The fact that the owner provided most of the construction labour means that many of the design details were worked out in the field.

The turbine design consists of a 35 kW, 1200 RPM Pelton wheel direct driving a 120/208 Volt 3 phase generator. There are twin adjustable nozzles for manual flow control to suit water availability. Fine control is provided by an electronic governor and load dump.

A.3.3 Contracting

There was only one main contract in the project, that of supplying and installing the turbine generator unit. The owner utilized other services on an "as required" basis.

A.3.4 Construction

As indicated above, the project was substantially constructed by the owner. The very rugged site led to some difficult work and a great deal more time was expended than initially allocated. Local materials were used for support and anchoring of the penstock: this is acceptable as long as the owner is prepared to undertake the necessary maintenance.

The limited use of a helicopter saved a great deal of time and effort in placing materials; a helicopter would have been required anyway, for loading the equipment from barge to powerhouse. Typically the cost of getting the helicopter to the isolated site is more than the actual cost of the work on site.

A.3.5 Operating Experience

Most of the CREDA report on the Nimmo Bay Project documents the operating experience of the plant. There have been numerous outages involving electronic, electrical, and mechanical components, but the overall time lost has been minimal. Some of the problems can be traced directly to mechanical design (bearings) while other problems, which have now been rectified, were more related to the unique operating conditions.

Problems with the civil works included debris clogging the intake, and periodic low flows. These problems, while being expected, do necessitate short term inconvenience. The problem of low flow is especially inconvenient, because the nozzle is only adjustable in increments rather than being continuously adjustable through a spear.

The other conceptual design problem was the selection of a three-phase generator instead of a single phase one. In a small installation such as this, the phases easily become imbalanced, which leads to generator problems. This problem may become more pronounced with the addition of a greenhouse or sauna, which adds a large heat load. Three phase power is necessary only when large (5 HP) motors are used; and this need is not foreseen in the Nimmo Bay situation.

The owner reported some difficulty in obtaining service from the supplier, along with difficulty in having the supplier finish the shutdown system. This raises the point that service for small hydro units will always be somewhat expensive because of isolation, but problems can be lessened by dealing with reputable local suppliers. Also, a protection system for overspeed or bearing failure should be installed at any location which cannot be attended to on short notice.

A.3.6 Project Summary

Nimmo Bay Resort Power Plant

Capacity: 35 kW

Gross Head: 64 m

Penstock:

  Length 250 m

  Sizes 240 m of 250 mm diameter PVC Series 100 and 125

  Intake: Timber weir and spillway across the stream. Inlet to one side.

  Powerhouse: 3.6 x 4.8 m building on concrete base.

  Turbine: 35 kW Peltech 975, 24.8 cm dia. wheel, twin nozzle supplied by Small Hydro Electrics Canada

  Generator: 40 kW Lima 1200 RPM
  120/208 V, 3 phase

  Governor: Thomson and Howe electronic with voltage, frequency, current and alarm monitor with load dump.

A.3.7 Construction Cost Summary

Powerhouse Equipment	$ 21,000	
Penstock	7,000	
Powerhouse	3,500	
Installation Labour	9,000	
Room and Board for Labour	2,500	
Transport: Barge delivery and helicopter offload	3,000	$ 46,000
Monitoring and information transfer		5,000
		$ 51,000

Notes: There are no estimates available for the owner's labour, design costs and incidentals. The above project cost would be considered among the least costly of any small hydro projects of comparable size. First year fuel savings of $11,200 amount to only an 11 kW average load; loads are expected to increase to improve the project economics.

B. PERMIT APPLICATIONS AND AGENCY ADDRESSES

CONTENTS

B.1 PERMITS

Water Licence	(Ministry of Environment)
Land Permits	(Lands Parks and Housing)
Cutting Permits	(Ministry of Forests)
Fisheries	(Federal and Provincial)
Electrical Inspection Branch	
Building Permit	(Sample - for case where works occur within municipal boundaries)

B.2 GENERAL INFORMATION

Energy Mines and Resources Canada
BC Utilities Commission

B.2 GENERAL INFORMATION

Concerning federal programs in renewable energy:

Energy, Mines and Resources Canada 666-5837
Programs Office
4th Floor - 900 W Hastings
Vancouver, BC
(until Sept. 30, 1989)

Energy, Mines and Resources Canada
New Energy Supplies Technology (NEST)
460 O'Connor Street
Ottawa, Ontario
(after Oct. 1, 1989)

Concerning policies for power sales:

BC Utilities Commission 660-4700
800 Smithe Street
Vancouver, BC

Concerning the purchase of electricity:

Interutility Marketing 663-2212
BC Hydro
9th Floor, 970 Burrard Street
Vancouver, B.C.

Commercial Affairs
West Kootenay Power
Box 130
Trail, B.C.

MINISTRY OF HIGHWAYS

Applications for Ministry of Highways Approval are only required where the works infringe on highway rights-of-way. Usually only the transmission line portion would be involved. The application would be initiated at the local district office, of which there is one in most towns in British Columbia.

ELECTRICAL INSPECTION BRANCH

Electrical Work must be done under permit and by persons holding proper licences. Usually the electrical contractor is responsible for obtaining the permit. After completion an inspection is arranged with the local electrical inspector by the contractor.

FISHERIES

Depending on the stream location, federal and/or provincial fisheries departments will have input into the location and construction details of instream works. These agencies are always referred to as part of the water licensing process, but it is sometimes worthwhile to discuss projects with the personnel in advance. This may save time later during the water licence approval process.

Federal Fisheries

Fisheries and Oceans 666-6566
Habitat Management Division
1090 W Pender Street
Vancouver, B C

Provincial Fisheries

Ministry of Environment 584-8822
Fish and Wildlife Branch
10334-152 A Street
Surrey, BC

NOTE: Many provincial agenices are located in common offices, so one call to one of the water licence offices listed may result in several contacts being made.

H. 20

THE GOVERNMENT OF THE PROVINCE OF BRITISH COLUMBIA

DEPARTMENT OF HIGHWAYS

Application for Permission to Construct Works within Crown Lands

I (We) hereby apply for permission to construct, use, and maintain works within the limits of Crown lands under the jurisdiction of the Minister of Highways, British Columbia, in accordance with the particulars, plans,* and specifications submitted herewith in *triplicate*. It is understood that the completion of this form constitutes an application only and that the works applied for will not be commenced until a covering permit has been issued. The proposed works consist of and are described as follows:—

†Have the necessary plans for approval been filed with the proper authorities?

Name of applicant

P.O. address

(Signed)
(Applicant.)

(Date)

To Local Office, Department of Highways

* *See* note No. 1 on back.
† *See* note No. 2 on back.

(OVER)

NOTE No. 1

The plans submitted may be blue-prints, and shall consist of key-map, general plan, profile, and where necessary detail plans on the following scales: **Key-map**, according to size of undertaking; **general plan**, 400 feet to an inch; **profile**, horizontal 400 feet to an inch, vertical 20 feet to an inch; **details**, on suitable scales. For minor undertakings, such as small water-pipes or culverts, etc., under a road, sketches will be accepted with sections and details as to dimensions, depth of cover, etc.

The plans shall supply at least the following information:—

(*a*) The boundaries of all Crown lands affected:

(*b*) The position of all existing public works within such boundaries and relative thereto and the name of the authority in control of same:

(*c*) The position of all private works (with names of owners) within such boundaries and relative thereto. (N.B.—Where the proposed works are upon or above the ground only such private works as are upon or above the ground, or as may be interfered with under the ground, need be shown):

(*d*) The proposed position within such boundaries and relative thereto which would be occupied by the works:

(*e*) The details of all tanks, manholes, lamp-poles, surface boxes, bridges, culverts, retaining-walls, or other structures to be constructed and used for the support of traffic, and details showing the method to be employed in supporting any proposed work, where any public works are affected:

(*f*) Full information showing exactly in what manner and to what extent it is proposed to use any land or works under the control of the Minister of Highways.

Specifications for the carrying-out of the work within the boundaries of all Crown lands shall also be submitted.

NOTE No. 2

When application is made in respect of the following works, the requisite particulars, plans, and specifications must be submitted to the proper authorities before the approval of the application by the Minister of Highways:—

Works	Authority to Whom Particulars, etc., Must Be Submitted	
1. Electrical undertakings—		
(*a*) Telegraph and telephone lines	Inspector of Electrical Energy	411 Dunsmuir St., Vancouver, B.C.
(*b*) Energy generated otherwise than by water-power	Inspector of Electrical Energy	
(*c*) Energy generated by water-power	Inspector of Electrical Energy	
	Comptroller of Water Rights	Parliament Bldgs., Victoria, B.C.
(*d*) Electrical railways	Inspector of Electrical Energy	411 Dunsmuir St., Vancouver, B.C.
	Deputy Minister of Railways	Parliament Bldgs., Victoria, B.C.
2. Steam-railways	Deputy Minister of Railways	" "
3. Logging-railways	Deputy Minister of Railways and also Chief Forester	" "
4. Skid-roads	Chief Forester	" "
5. Sewerage and sewage-disposal	Deputy Minister of Health	" "
6. Water-supply for domestic purposes	Deputy Minister of Health and also Comptroller of Water Rights	" "
7. Waterworks undertakings other than for domestic supply	Comptroller of Water Rights	" "
8. Works to be constructed within any municipality	Municipal Official.	

MINISTRY OF ENVIRONMENT

Water Management Branch, Parliament Buildings, Victoria, B.C. V8V 1X5

INFORMATION REGARDING APPLICATIONS FOR WATER LICENCES

In order to help you fill in a water application correctly, a few suggestions are set out below:

Application forms must be completed in full. It is particularly important that the quantity of water required is shown.

Domestic purpose: "Means the use of water for household requirements, sanitation, and fire prevention, the watering of domestic animals and poultry, and the irrigation of a garden not exceeding one quarter of an acre adjoining and occupied with any dwelling-house."

The normal requirement for one household, including the irrigation of a small garden, is 500 gallons a day. However, if the watering of poultry and domestic animals other than pets is included, water requirements may be 1,000 gallons a day.

Irrigation purpose: "Means the beneficial use of water on cultivated land and hay meadows for nourishing crops."

The quantity needed should be stated in acre-feet per annum. An acre-foot of water is the quantity which will cover 1 acre, 1 foot in depth.

As quantities required for irrigation vary depending on local climate and conditions, the following general guide should be used:

Climate	Quantity Required
Wet or cool	1 acre-foot per acre
Semidry or warm	2–3 acre-feet per acre
Dry or hot	3–4 acre-feet per acre

Thus, if you live in a dry or hot area and wish to irrigate 10 acres you should apply for 40 acre-feet.

Any advice you need regarding water applications can be obtained from the Water Management Branch offices in the Provincial Government Buildings, at Victoria, Kamloops, Nelson, and at 1905 Kent Road, Kelowna, B.C.; 313 Sixth Street, New Westminster, B.C.; and 1011 Fourth Avenue, Prince George, B.C. Advice may also be obtained from any of the Water Recorders listed below.

Water District	Water Recorder and Mailing Address	Telephone	Regional Engineer
Alberni	4515 Elizabeth Street, Port Alberni V9Y 6L5	723-3501	Victoria
Ashcroft	Box 70, Clinton V0K 1K0	453-2412	Kamloops
Atlin	Box 100, Atlin V0W 1A0	651-7577	Prince George
Cariboo	540 Borland Street, Williams Lake V2G 1R8	392-6261	Kamloops
Cranbrook	100—11th Avenue South, Cranbrook V1C 2P2	426-8431	Nelson
Fernie	Box 340, Fernie V0B 1M0	423-6845	Nelson
Golden	Box 39, Golden V0A 1H0	344-6817	Nelson
Grand Forks	Box 850, Grand Forks V0H 1H0	442-8642	Kelowna
Hazelton	Box 340, Smithers V0J 2N0	847-4411	Prince George
Kamloops	7 West Seymour Street, Kamloops V2C 1E5	372-5233	Kamloops
Kaslo	Box 580, Kaslo V0G 1M0	353-2338	Nelson
Liard	1201—103 Avenue, Dawson Creek V1G 4J2	782-5931	Prince George
Nanaimo	Courthouse, Nanaimo V9R 5J1	754-2111	Victoria
Nelson	Box 730, Nelson V1L 5R5	352-2211	Nelson
New Westminster	100—403 Sixth Street, New Westminster V3L 3B1	525-0375	New Westminster
Nicola	Box 339, Merritt V0K 2B0	378-9944	Kamloops
Peace River	1201—103 Avenue, Dawson Creek V1G 4J2	782-5931	Prince George
Penticton	Courthouse, Penticton V2A 5A5	492-2782	Kelowna
Prince George	1600 Third Avenue, Prince George V2L 3G6	562-8131	Prince George
Prince Rupert	Courthouse, Prince Rupert V8J 1B7	624-2121	Prince George
Princeton	Box 9, Princeton V0X 1W0	295-6151	Kelowna
Quesnel	102—350 Barlow Avenue, Quesnel V2J 2C1	992-5591	Prince George
Revelstoke	Box 380, Revelstoke V0E 2S0	837-3222	Nelson
Vancouver	222, 800 Hornby Street, Vancouver V6Z 2C5	668-2654	New Westminster
Vernon	Courthouse, Vernon V1T 4W5	545-2387	Kelowna
Victoria	Parliament Buildings, Victoria V8V 1X5	387-3413	Victoria

If your application is not correctly completed you may be required to make out a new application at a later date.

FILE WITH WATER RECORDER

FOR WATER RECORDER STAMP

Application for a Water Licence

WATER ACT

(Section 8)

I/we ....
(Full name or names, if land owned jointly.)

of ....
(Mailing address)

hereby apply to the Comptroller of Water Rights for a licence to {divert and use / store} water out of

.... which flows ....
(Name of creek, lake, or spring.) (Direction of flow.)

and discharges into .... and give notice of my application to all persons affected.

{The point of diversion / The storage dam} will be located at ....
(Give distance and direction from some surveyed or known point.)

The quantity of water to be diverted or stored is ....
(Cubic feet per second, gallons per day, or acre-feet per annum.)

The purpose for which the water will be used is ....

The land or mine on which the water will be used is Lot ....
(Full and correct legal description)

....

A copy of this application was posted on the ...., 19 ....
(Day.) (Month.)

at the proposed point of diversion or site of the dam and on the land or mine where the water is to be used

and two copies will be filed in the office of the Water Recorder at ....
British Columbia.

Objections to this application may be filed with the said Water Recorder or with the Comptroller of Water Rights, Parliament Buildings, Victoria, B.C. V8V 1X5, within thirty days of the serving of a signed copy of the application.

....
Applicant.

By ....
Agent.

....
Agent's address.

IMPORTANT

Every applicant must do the following:

(1) *Post the application on the ground*, that is, in conspicuous places at or near the proposed point of diversion, site of the dam (if any), and place of use.

(2) *File two copies with the Water Recorder* in whose district the point of diversion will be, within twenty days of the posting on the ground.

(3) Within ninety days of the posting of the application on the ground, serve signed copies on all owners of land or mining property that will be affected physically by the proposed works or by the operation or utilization thereof, and on all licensees or prior applicants whose points of diversion are at or below the applicant's proposed point of diversion.

All copies must be signed and completed by filling in the blanks in the above form; and, in addition, the two copies filed with the Water Recorder must contain a sketch showing the applicant's land, the location of the point of diversion and the dam (if any), and all land touched or crossed by the works, and the additional information indicated on the other side of this form.

Both sides of the two copies filed with the Water Recorder must be fully and correctly completed or the application may have to be returned.

It is advisable to file the application with the Water Recorder as soon as possible after posting it on the ground because the date of filing will, in most cases, determine the priority of the licence that may be issued.

NOTE.—This sheet need only be completed on the two copies of the application filed with the Water Recorder.

To the Comptroller of Water Rights:

In support of my application for a water licence I submit the following information:—

(1) My title to the place of use is ....
(Whether registered owner, agreement holder, pre-emptor, etc.)

(2) The proposed works will be ....
(Give general description—pump, pipe, ditch, etc.)

....

....

....

(3) The dam to be constructed will be a .... dam, and
(Type.)

will be ....feet in height, and .... feet in length.

(4) The maximum area of the reservoir will be .... acres.

(5) The depth of storage at the dam, from bottom of sluice-pipe to crest of the spillway, will be .... feet.

(6) The head of water to be used will be .... feet.
(For power and hydraulic mining only.)

(7) The area of land to be irrigated will be ....acres.

(8) (*a*) The works will be entirely on my own property, or

(*b*) The works will affect physically the property of the following owners:—

Name of Owner, Including the Crown	Legal Description of Land	Area Required for Works	
		Length	Breadth

Sketch, showing applicant's land and all other land touched by the works or flooded, also the location of the point of diversion and other works, including buildings to be served with water, if applicable, and the lengths of all ditches, flumes, and pipes.

N.

W. E.

S.

.... *Applicant.*

.... *Agent.*

WRB 4

W 348

Province of British Columbia | Ministry of Lands, Parks and Housing

APPLICATION FOR CROWN LAND

PLEASE PRINT

INDIVIDUAL(S) NAME(S) GIVEN NAME(S) (* INDICATE JOINT TENANCY IF DESIRED) ▶

OR COMPANY NAME

ADDRESS ▶ (* FURNISH BOTH STREET AND MAILING)

APT. NO. | STREET NO | STREET | POST OFFICE BOX NUMBER

CITY · TOWN | PROVINCE | POSTAL CODE

DATE STAMP

PHONE | AREA CODE | SOCIAL INSURANCE NO | COMPANY INC NO

AGE 19 YEARS AND OVER YES ☐ NO ☐ | CANADIAN CITIZEN YES ☐ NO ☐ | RESIDENT IN BRITISH COLUMBIA FOR 2 YEARS YES ☐ NO ☐

LOCATION OF CROWN LAND ▶ | AREA · HECTARES

CROWN LAND IS

☐ SURVEYED GIVE LEGAL DESCRIPTION

OR

☐ UNSURVEYED GIVE METES AND BOUNDS DESCRIPTION

NOTE ▶ 1. ATTACH PRELIMINARY DEVELOPMENT PLAN 2. ATTACH A SKETCH MAP OF AREA

PURPOSE FOR CROWN LAND ▶

IS LAND ACCESSIBLE ▶ BY PUBLIC ROAD ☐ YES ☐ NO | IF NO STATE ACCESS PLAN

DATE LAND STAKED ▶

OTHER CROWN LAND HOLDINGS ▶ ANY OTHER CROWN LAND HELD BY APPLICANT OR SPOUSE ☐ YES ☐ NO | IF YES STATE TYPE AND TENURE

APPLICANT DECLARATION ▶ I HEREBY CERTIFY THAT ALL INFORMATION GIVEN IN THIS APPLICATION FOR CROWN LAND IS TRUE AND CORRECT

OCCUPATION (IF INDIVIDUAL(S)) OR CORPORATE POSITION (IF COMPANY) —

DATE | APPLICANT SIGNATURE(S)

FOR OFFICE USE ONLY

DATE APP REC'D DAY MTH YR | DISTRICT OFFICE | APPLICATION IS ☐ NEW ☐ RENEWAL | FILE NO

APPLICATION IS ☐ LAND ACT ☐ MINISTRY ACT | LAND IS IN ☐ PLANNED AREA ☐ UNPLANNED AREA ☐ PROVINCIAL FOREST | APPLICATION FOR ☐ FORESHORE ☐ OTHER LAND | PRELIMINARY ESTIMATE OF LAND VALUE $

TYPE OF TENURE FOR APPLICATION

[illegible] | LICENCE OF [illegible] | ☐ EASEMENT RIGHT OF WAY [illegible] GRANT | ☐ LETTERS [illegible] | [illegible] | ☐ PREPAID LICENCE OF OCCUPATION

DISTRICT OFFICE
FILE COPY

Province of
British Columbia

Ministry of Lands
Parks and Housing

FORM NO. 1

LAND ACT

NOTICE OF INTENTION TO APPLY FOR A DISPOSITION OF CROWN LAND

In Land Recording District of ____________________

*Here describe by giving name of lake, mountain, stream, village, etc., in vicinity

and situated* ____________________

Take notice that ____________________,

of ____________________, occupation ____________________,

intends to apply for a ____________________ of the following described lands:

Where land is surveyed and evidence of survey is available complete *(a)*.

(a) [*Give legal description*] ____________________

____

____

____________________ containing __________ ha __________.

or

Where land is unsurveyed or where no evidence of survey is available complete *(b)*

†Locate with reference to some survey post if possible

(b) Commencing at a post planted† ____________________

____

____

____

thence ____________________; thence ____________________;

thence ____________________; thence ____________________;

and containing ____________________ ha more or less.

‡Be as specific as possible

The purpose for which the disposition is required is ‡ ____________________

____

____
(Name of applicant in full)

____
(Name of agent if applicable)

Dated ____________________ 19 ____

STAKING CROWN LAND

Before making an application for Crown Land

- where the land is unsurveyed or is part of a surveyed parcel and the point of commencement is not a surveyed corner

an applicant is required to identify the land by the process of staking.

This is done by attaching the hard copy of this form to a post, at least a meter high above ground, firmly fixed in the ground at one corner of the land.

An application for Crown Land must then be filed within 30 days of staking with a Land Commissioner.

NOTE: THERE IS NO RIGHT ACQUIRED WHATSOEVER TO ANY CROWN LAND BY REASON OF:

- STAKING THE LAND
- PUBLISHING A NOTICE OF INTENT TO APPLY FOR CROWN LAND
- FILING AN APPLICATION FOR CROWN LAND.

DESCRIBING A STAKED LAND AREA

1. Boundary lines of the staked area must be, as much as possible,
   - astronomically true north, south, east and west so that a rectangular lot is formed
   - in multiples of 200 meters with the smallest allowable jog being, in exceptional cases, 100 meters.
2. Where the topographical features of the area do not allow for rectangular boundary lines running true north, south, east and west, then boundaries will be permitted in other directions as long as they do not interfere with the orderly survey of other surrounding land.
3. The side lines for small parcels fronting on lakes, rivers, tidal waters and on certain surveyed highways shall, where possible, be parallel to each other and perpendicular to the general trend of the features on which the small parcel fronts.
4. The side lines for unsurveyed foreshore shall, as a general rule, be laid out at right angles to the general trend of the shore. This may be varied to suit special conditions, but encroachment on the foreshore fronting adjoining lands shall be avoided. The outside or waterward boundary shall be a straight line or series of straight lines joining the outer ends of the side boundaries. On narrow bodies of water the outside boundary shall not normally extend beyond the near edge of the navigable channel.

Contact the ministry regional office

They can provide you with full information and details concerning the approval process.

CARIBOO
172 North 2nd Avenue
Williams Lake, B.C.
V2G 1Z6 Phone: 392-6261

KOOTENAYS
828-A Baker Street
Cranbrook, B.C.
V1C 1A2 Phone: 489-4333

LOWER MAINLAND
4240 Manor Street
Burnaby, B.C.
V5G 1B2 Phone: 438-5344

OMINECA
1011 4th Avenue
Prince George, B.C.
V2L 3H9 Phone: 562-8131

PEACE
2nd Floor, 9830 100th Avenue
Fort St. John, B.C.
V1J 1Y5 Phone: 787-1111

SKEENA
3794 Alfred Avenue
Smithers, B.C.
V0J 2N0 Phone: 847-4411

THOMPSON-OKANAGAN
348 Tranquille Road
Kamloops, B.C.
V2B 3G6 Phone: 554-3144

VANCOUVER ISLAND
#404-3960 Quadra Street
Victoria, B.C.
V8X 4A3 Phone: 479-8288

MINISTRY OF FORESTS

Even after securing a right to occupy Crown Land a licence to cut is still required if trees are to be removed

Region	Offices Address	Phone
Vancouver	4595 Canada Way Burnaby, BC	299-9151
Prince Rupert	Bag 5000 3726 Alfred Street Smithers, BC V0J 2N0	847-4511
Prince George	1011 Fourth Avenue Prince George, BC V2L 3H9	565-6100
Kamloops	515 Columbia Street Kamloops, BC V2C 2T7	828-4131
Nelson	518 Lake Street Nelsen, BC V1L 4C6	398-4345
Cariboo	540 Borland Street Williams Lake V26 1R8	392-6261
Victoria	Ministry of Forests Legislative Buildings Victoria, BC V8V 1X5	387-5985

NOTE: There are numerous forestry field offices, for which the regional office would be able to supply information once a project location is determined.

Province of British Columbia
Ministry of Forests
FOREST SERVICE

Application for a Licence to Cut

Pursuant to Section 47 of the Forest Act
(Three copies to be completed.)

Regional Manager, Date ...., 19 ......

................................, *British Columbia.*

I/We hereby apply for a licence to cut from the following area ....

....

....

Land District, occupied under the following tenure:

Agricultural lease .... ☐
Industrial lease .... ☐
Pre-emption .... ☐
Grazing lease .... ☐
Access road R. of W. .... ☐
Easement .... ☐
Agreement to purchase .... ☐
Mineral claim .... ☐
Residential lease .... ☐

File No. .... and/or Lease No. ....

Other tenure (specify) ....

Estimated volume of timber ....

If the area is unsurveyed please show sketch on reverse side.

Applicant's name ....

Address ....

....

Quote full names of partners, if any:

....

....
(Applicant's signature.)

FOREST SERVICE USE

Victoria File .... Atlas Ref. ....

District .... Location ....

Licence to Cut No. .... Land Manager ....

FOREST SERVICE USE (VICTORIA)

....

....

....

....

....

....

....

....

F.S. 321—31M 81/10 *Signature for Administrative Officer, Timber Management.*

[illegible] GRID COORDINATES			[illegible]tory		
Zone	East	North	Region	Compt	
				No	L

Indicate Scale Used

MANAGEMENT UNIT		TIMBER SUPPLY AREA		Pulpwood Agreement	Cascodes	
Type		Number				
Number		Block			East	
Block		Sub-B			West	

BUILDING PERMIT

The attached form is an example from one municipality. Where a proposed project falls within municipal boundaries, the project owner should contact the local authorities for any detailed requirements.

CORPORATION OF [illegible]
MUNICIPAL HALL

BUILDING DEPARTMENT

APPLICATION FOR BUILDING PERMIT

____

PERMISSION IS HEREBY APPLIED FOR TO ERECT ________ ADDITION ________ ALTER ________ DEMOLISH ________ REMOVE ________ THE FOLLOWING BUILDING UNDER THE PROVISIONS OF THE BUILDING BYLAW AND ALL OTHER STATUTES AND BYLAWS IN FORCE IN THE DISTRICT OF

ADDRESS OF PROPERTY ____________________

LEGAL DESCRIPTION OF PROPERTY ____________________

____

OWNER ____________________ ADDRESS (MLG) ____________________
PLEASE PRINT

CONTRACTOR ____________________ ADDRESS ____________________
PLEASE PRINT

PURPOSE FOR WHICH BUILDING IS TO BE USED ____________________ ____________________

____________________ SIZE: ____________________ NO. OF FLOORS ________

INTERIOR FINISH: DRYWALL ☐ PLASTER ☐ WOOD ☐ EXTERIOR FINISH: STUCCO ☐ SIDING ☐ ________

BASEMENT: YES ☐ FULL ☐ PART ☐ CRAWLSPACE ☐ ________ TYPE OF HEATING GAS ☐ OIL ☐ OTHER ________

ESTIMATED COST OF WORKS (TOTAL COST OF WORKS READY FOR OCCUPANCY EXCLUDING LAND AND INCLUDING LABOUR) $ ________

FEE $ ________

BOND CASH ☐ CERTIFIED CHEQUE ☐ LETTER OF CREDIT ☐

PLOT PLAN

ALL WORK MUST BE DONE BY A PERSON(S) HOLDING A LICENSE FOR THE CURRENT PERIOD, ISSUED BY THE LICENCE DEPARTMENT, EXCEPT IN THE CASE OF AN OWNER WHO PERSONALLY DOES THE WORK.

If, the permit applied for, is granted, I agree to conform to the requirements of the Building Bylaw, and all other Statutes and Bylaws in force in the Corporation of the District of , and to indemnify and release the Corporation from all claims, liabilities, judgements, costs and expenses of whatsoever kind, which may accrue against the Corporation of the District of , in consequence of, and incidental to, the granting of this Permit, if issued.

NOTE: An approved access (driveway entrance) must be installed at the site, before a building permit may be issued, if required by the Engineering Dept.

A Floor, & elevation plan must accompany this application.

PRINT NAME OF APPLICANT: ____________________

____________________ ____________________
SIGNATURE OF APPLICANT PHONE NUMBER

FOR OFFICE USE ONLY

SEWER ☐ WATER ☐
SEPTIC TANK ☐ WELL ☐

BUILDING DEPARTMENT COMMENTS

____

____

____

____

____

____

C. SMALL HYDRO SUPPLIERS

CONTENTS

C.1 MATERIALS

- Powerhouse Equipment
- Penstock Material
- Electrical Components

C.2 INSTALLATION SERVICES

- Foreword
- General Contractors
- Specialty Contractors

C.1 MATERIALS

Powerhouse Equipment

Turbines and Packages

American Cross-FLow
Suite 401, 110 West Ocean Boulevard
Long Beach, California
90802

Barber Hydraulic Turbines
P O Box 340, Barber Drive
Port Colburne, Ontario
L3X 5W1

Brown Boveri Howden
1510 Birchmount
Scarborough, Ontario
M1P 2G6

Canyon Industries
5346 Mosquito Lake Road
Deming, Washington
98244

CPI Equipment
21869 56th Avenue
Langley, B.C.
V3A 7N6

Dependable Turbines Ltd
7 - 3005 Murray Street
Port Moody, B.C.
V3H 1X3

Dominion Bridge-Sulzer Inc.
555 Notre Dame Street
Lachine, Quebec
H8S 4E7

Dynamic Engineering Inc.
1270 Francis Street
Vancouver, B.C.
V6A 1Z5

Electric Power Equipment Ltd
1285 Homer Street
Vancouver, B.C.

Flygt Canada
74 Glacier Street
Coquitlam, B.C.

Galt Energy Systems Ltd.
Suite 503, 73 Water Street North
Cambridge, Ontario
N1R 7L6

Gilkes Inc.
Electric Power Equipment
1285 Homer Street
Vancouver, B.C.
V6B 2Z2

Hart Mayall & Associates
Box 31
Tatla Lake, B.C.
V0L 1V0

Highland Irrigation Ltd.
Williams Lake,
Kamloops, and Cloverdale

Hymac Machine
100 Barrick Road
Port Colborne, Ontario
L3K 5Z5

C.P. Koch Ltd.
8932 Oak Street
Vancouver, B.C.
V6P 4B7

Al Kotowick
250 E.36th Avenue
Vancouver, B.C.
V5W 4A1

Leroy Somer-Hydrolec
925 Leroy Somer Boulevard
Granby, Quebec
J2G 8E2

North American Turbine Co Inc
3140 W Warner Avenue
Santa Ana, California
92704

Richards' Hydro-Tech Inc.
Box 1259
Summerland, B.C.
V0H 1Z0

Gordon Russell Ltd.
7600 Alderbridge Way
Richmond, B.C.
V6X 2A2

Small Hydroelectrics
5141 Wickersham Street
Building 10
Acme,Washington
98220

Solace Energy Center Ltd
4025 E Hastings Street
Burnaby, B.C.
V5C 2J1

Tsolum Power
708 - 1155 West Pender Street
Vancouver, B.C.
V6E 2P4

Generators and Controls

Kato Engineering
(Finning Power Products)
555 Great Northern Way
Vancouver, B.C.

Schmidtec Power Systems Ltd.
19214 - 94 Street
Surrey, B.C.

Simpson Power Products
5271 Regent
Burnaby, B.C.

Simson-Maxwell Ltd
1380 - 6th Avenue
Vancouver, B.C.

Governors

Thomson and Howe Energy Systems Inc.
Site 17, Box 2, SS 1
Kimberley, B.C.
V1A 2Y3

Woodward Governor Company
5001 N Second Street
Rockford, Illinois
61101

NOTE: The following list is representative of suppliers of various components, but there are many others. Prices and availability may vary from region to region in BC, and may also vary with the quantity purchased.

Penstock Material

Polyethylene Pipe

Dupont of Canada
1550 Alberni Street
Vancouver, B.C.

Pacific Poly-Pipe Products Ltd.
2 - 12091 No.5. Road
Richmond, B.C.
V7A 4E9

Prolite Plastics Ltd.
4312 Norfolk
Burnaby, B.C.

PVC Pipe

International Plastics Ltd.
12180 Vickers Way
Richmond, B.C.

Manville Canada Inc.
9747 - 1994 Street
Langley, B.C.

Rehau Industries Inc.
103 - 20359 Langley By Pass
Langley, B.C.

Scepter Manufacturing Co. Ltd.
731 Derwent Way
Annacis Island, B.C.

Steel Pipe

IPSCO
215-409 Granville Street
Vancouver, B.C.

Pipe and Piling Supplies (BC) Ltd.
1835 Kingsway
Port Coquitlam, B.C.

Westlund Industrial Supply Ltd.
340 Ewen
New Westminster, B.C.

Miscellaneous

Canron Inc.
20460 Duncan Way
Langley, B.C.

Valves and Fittings

Note: Most of the pipe supply companies can also supply valves and fittings. In addition:

Fleck Bros
4084 McConnell Court
Burnaby, B.C.

Robar Industries (Repair Clamps)
12945 - 78 Avenue
Surrey, B.C.

Terminal City Iron Works
1909 Franklin
Vancouver, B.C.

Electrical Components

Poles

Bell Pole Co
23562 River Road
Maple Ridge, B.C.

MacMillan Bloedel
Wood Preserving Division
180 Ewen
New Westminster, B.C.

Wire

Alcan Canada Products
1285 W Pender Street
Vancouver, B.C.

Anixter Canada Inc
4255 Phillips
Burnaby, B.C.

Canada Wire and Cable Ltd
1500 - 1066 W Hastings
Vancouver, B.C.

Pole Line Fittings

Trydor Sales
1117 Franklin
Vancouver, B.C.

Electrical Fixtures

Gough Electric
2770 Bentall
Vancouver, B.C.

E B Horsman
1150 Raymur
Vancouver, B.C.

C.2 INSTALLATION SERVICES

C.2.1 Foreword

The following list of contractors was based on the author's direct experience with small hydro builders as well as the results of a notice posted with the Amalgamated Construction Association. The notice met with a poor response and the general experience with contractors in small remote jobs is that the company which may be the low bidder, or even the companies which may submit bids, are unpredictable.

Accordingly, you may wish to use this list as a starting point, but you should also contact other contractors and perhaps advertise if the job is large enough, to ensure that you attract the lowest qualified bidder.

Works can generally be divided into an "Intake, Penstock, Powerhouse" contract which requires the skills of pipe layers, welders, concrete workers and building construction workers; and "Electrical Installation", which requires the services of a Class A electrician and perhaps a lineman.

C.2.2 General Contractors

1. Highland Energy Systems Ltd
7 - 3005 Murray Street
Port Moody, B.C.

2. R DeVito Construction
4606 Bowness Avenue
Powell River, B.C.

3. Gretzinger MacDonald Construction Ltd
790 Birch
Campbell River, B.C.

Specialty Contractors - Piping (based on Advertisement Response)

Allied Engineering Works Ltd
575 Pembroke Street
Victoria, B.C.

Western Fire Suppression
7590 - 149 A Street
Surrey, B.C.

D. SMALL HYDRO CONSULTANTS

Many "small hydro consultants" have "hands on" experience and have built small systems, while many owner builders are not listed as consultants but who may be an invaluable source of information.

The Association of Professional Engineers of BC. and the Association of Consulting Engineers of Canada may be able to provide names of local engineers who could help. Also, local irrigation districts, utility offices, and water management offices may know of owners and consultants in your vicinty.

D.1 LIST OF CONSULTANTS

Acres International Ltd
Appropriate Power Engineering Corporation
Roy Campbell Ltd
Crippen Consultants Ltd.
Patrick Fawkes
Ian Hayward and Associates
Colin Holt, Consultants
Ker Priestman Associates
Klohn Leonoff Consultants
R D McDougall and Associates
Robert Mathews, MOHA Technical
Monenco Consultants Pacific
Sigma Engineering Ltd
Wescrow Engineering Consultants Ltd
Willis Cunliffe Tait/Delcan

ACRES INTERNATIONAL LTD.
4th Floor, 845 Cambie Street
Vancouver, B.C.
V6B 2P4

APPROPRIATE POWER ENGINEERING CORPORATION
4697 Woodview Place
West Vancouver, B.C.
Attention: J R Breckon

ROY CAMPBELL LTD.
612 Marine Drive
West Vancouver, B.C.
V7T 1C9

CRIPPEN CONSULTANTS
#900 - 401 W.Georgia Street
Vancouver, B.C.
V6B 5E1

PATRICK FAWKES
6994 Hycroft Road
West Vancouver, B.C.
V7N 2H8

IAN HAYWARD AND ASSOCIATED LTD.
1 - 1500 Marine Drive
North Vancouver, B.C.
V7P 1P7

KER PRIESTMAN AND ASSOCIATES
601 - 1190 Hornby Street
Vancouver, B.C.
V62 2K5

KLOHN LEONOFF CONSULTANTS LTD.
10180 Shellbridge Way
Richmond, B.C.
V6X 2W7

R D McDOUGALL AND ASSOCIATES
206 - 508 Clarke Road
Coquitlam, B.C.
V3J 3X2

MONENCO CONSULTANTS PACIFIC LTD.
701 - 1199 W Pender Street
Vancouver, B.C.
V6E 2R1

SIGMA ENGINEERING LTD.
801-1155 West Georgia Street
Vancouver, B.C.
V6E 3H4

UMA ENGINEERING LTD.
1066 West Hastings Street
Vancouver, B.C.

WESCROW ENGINEERING CONSULTANTS LTD.
202 - 1515 Pemberton Avenue
North Vancouver, B.C.
V7P 2S3

WILLIS CUNLIFFE TAIT/DELCAN
827 Fort Street
Victoria, B C
V8W 1H6

E. SMALL HYDRO COMPUTER PROGRAMS

E.1 CONSULTANT PROGRAMS

Several of the engineering companies listed previously have in-house computing capability and have developed their own programs which have either been adapted for small hydro or developed exclusively for small hydro. These include programs for hydrology, capacity selections, penstock size, reservoir analysis, and cost analysis. The net costs of a run are usually nominal but they do involve the use of engineering staff for the data assembly, input and interpretation.

Services available from:

ACRES INTERNATIONAL LTD
APPROPRIATE POWER ENGINEERING CORPORATION
CHARLES HOWARD & ASSOCIATES LTD.
ENERGY, MINES AND RESOURCES CANADA
KER PRIESTMAN AND ASSOCIATES
KLOHN LEONOFF CONSULTANTS LTD
MONENCO CONSULTANTS PACIFIC
SIGMA ENGINEERING LTD

ACRES INTERNATIONAL LTD.

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
HYDR 130	Flow Duration Curve Analysis	*	ACRES
HYDR 205	Flow Duration and Turbinable Flow Analysis		ACRES
HYDR 253	Stream Flow Linear Correlation Program		ACRES
HYDR 305	Waterhammer & Surge Analysis		ACRES
HYDRHEC 1	"HEC 1" Flood Hydrograph Package		ACRES
HYDRHYDUR	Flow Duration Curve Based on Power & Energy Program		ACRES
HYDRHYMO	Hydrologic Modelling for Surface Runoff from Watersheds		ACRES
HYDRSSARR	Streamflow Simulation and Reservoir Regulation		ACRES

*All programs can be run on any VT 100 or equivalent terminal.

ACRES also has an additional 40 to 50 in-house hydrological and cost analysis programs for complex projects.

Costs are usually less than $100.00 per run plus operator's input time.

APPROPRIATE POWER ENGINEERING CORPORATION

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
	Programs available in hydrology hydraulics and structures	Micro and Main Frame	Appropriate Power

CHARLES HOWARD & ASSOCIATES LTD.

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
IMP	Integrated Method for Power Analysis Series of Programs for Precipitation, Stormflow, Flood Frequency, Power System Analysis and, System Optimixation: Graphical Output of above.	IBM PC XT	CHA/ EMR

ENERGY, MINES AND RESOURCES CANADA

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
IMP	Integrated Method for Power Analysis Series of Programs for Precipitation, Stormflow, Flood Frequency, Power System Analysis and, System Optimixation: Graphical Output of above.	IBM PC XT AT	CHA for EMR
SHYDRO	Small Hydro Costing Analysis Basic cost data integrated for a personal computer.	IBM	EMR

KER PRIESTMAN AND ASSOCIATES

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
HYETOG	Hyetograph program to create and manipulate KPA's standard hyetograph files. Used in conjunction with ILLUDAS, HYDROG, HYPLOT. Uses rainfall Intensity, duration curves and rainfall distribution curves.	IBM PC or DEC PDP-11	KPA
HYDROGROG	Hydrograph program to create and manipulate KPA's standard hydrograph files. Calculates hydrographs for undeveloped basins, permits manual entry of hydrographs and accommodates 2 reservoir routing methods. Allows addition, subtraction of hydrograph and multiplication of hydrograph by a constant.	IBM PC or DEC PDP-11	KPA
HYPLOT	Converts KPA standard hydrograph and hyetograph files to graphic plot files.		KPA
	Calculates areas and volumes from digitizer input.	HP-9030 (has digitizer capability)	KPA
	Other cut-fill and cross section plot programs are available.		KPA
SURNAL	Waterhammer Analysis		Marketed by Control Data Corporation

KLOHN LEONOFF CONSULTANTS LTD

Proprietary programs available on request.

MONENCO CONSULTANTS PACIFIC LTD.

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
SHYDRO	Small Hydro Design and Cost Estimating	Digital Equipment	MONENCO

SIGMA ENGINEERING LTD.

Program Name	Description	Type of Computer Equipment Needed and Cost per Run	Developer
SH 1	Uses basic data from 1:50,000 mapping, to provide system sizes and preliminary costs.	IBM-PC	SIGMA
SH 2	Uses stream flow, load and power output variables to provide optional plant size in mixed hydro/diesel system.	IBM-PC	SIGMA

Programs are customized to individual situations and in-house programming capability available.

E.2 PROPRIETARY PROGRAMS

The following programs are available for purchase by the small hydro developer using readily available computer equipment.

1. BROADUS, C.R., 1981, "Hydropower Computerized Reconnaissance Package Version 2.0". Contract Report DOE, Contract No. DE-AC07-761 DO 1570, Idaho Falls, Idaho, Idaho National Engineering Laboratory, U.S. Dept. of Energy.

   This program runs on an APPLE computer and although costs are not available, they are expected to be nominal because the development was sponsored under government contract

2. IDEAL ENERGY CONSULTANTS, 4490 W. 11 Avenue, Vancouver, B.C.. V6R 2M3 "Small Hydro Design".

   This program runs on an HP 41 CV calculator. It takes input variables of gross head, penstock length and pipe type, efficiency, expected head loss and pipe diameter, flow or power output. Other variables are then automatically calculated. The program provides input and output in English or metric units. Cost: $182. Includes program cards, keyboard overlay, instruction book.

F. DEFINITIONS

ALTERNATING CURRENT (ac,AC) - Electricity that reverses its direction of flow periodically, as contrasted to DIRECT CURRENT.

AMORTIZATION - The paying of a debt with installment payments or with a SINKING FUND. Also writing off expenditures by prorating them over a period.

AVAILABILITY FACTOR - The percentage of time a plant is available for power production.

AVOIDED COST - The payment made for the capacity and energy of a small power project; such payment equals the cost to a utility of obtaining and operating additional generating units, or to purchase power from another source, if this power were not available. Also called avoidable cost. Can also be considered as the value of fuel and maintenance saved by displacing diesel generation with hydro power.

BASE LOAD - The amount of electric power needed to be delivered at all times and all seasons.

BENEFIT-COST RATIO (B/C) - The ratio of the present value of the benefit (e.g. revenues from power sales or value of displaced diesel generation costs) to the present worth of the project cost.

CAPACITY - The maximum power output or the load for which a generating unit, generating station, or other electrical apparatus is rated. Common units include kilovolt-ampere (kVA), KILOWATT (kW), and MEGAWATT (MW).

CAPACITY FACTOR - The ratio of the energy that a plant produces to the energy that would be produced if it were operated at full capacity throughout a given period, usually a year.

CAPITAL COST - The total cost of a project from the conceptual to the completion stage including initial studies, management, equipment cost, construction and materials costs, start-up fees, supervision and interest during construction.

CAPITALIZED COST - A method used to compare the costs of alternatives; it is equal to the sum of the initial costs and the present worth of annual payments, such as operation and maintenance costs.

CAPITAL RECOVERY FACTOR (CRF) - A factor used to convert an investment into an equivalent annual cost at a given interest rate for a specified period.
(CRF) X (LOAN AMOUNT) = Annual Cost.

CAVITATION - An hydraulic condition which may result in pitting of metal surfaces due to the action of water pressure being reduced to the vapour pressure at the given temperature and elevation. Vapour implosions cause the metal pitting. It can occur in reaction turbines which are set too high above tailwater and in some valves which are operated partially open.

CFS - See CUBIC FEET PER SECOND.

CIRCUIT BREAKER - A switch that automatically opens to cut off an electric current when an abnormal condition occurs.

CIVIL WORKS - All the works of a facility associated with plant structures, intake works and water conveying.

COUPLINGS - A mechanical linkage between the turbine shaft and the generator shaft.

CUBIC FEET PER SECOND (cfs, ft^3/s) - A flow equal to 539,000 Imp. gallons per day or 0.028317 cubic metres per second (m^3/s).

DEMAND - The electrical energy requirement of a system or of a part of a system, or of a piece of equipment; it is usually expressed in KILOWATTS, MEGAWATTS, etc.

DESIGN LOAD - The HEAD at which the RUNNER of a turbine is designed to provide the required guaranteed output, usually close to the highest efficiency.

DIRECT CURRENT (dc, DC) - Electricity that flows continuously in one direction, as contrasted with ALTERNATING CURRENT.

DRAFT TUBE - A large tube that takes from a TURBINE, the water discharged at a high velocity, and reduces its velocity by enlarging the cross-section of the tube, to provide a gain in net head.

EFFICIENCY - The ratio of the output to the input of energy or power; usually expressed as percentage.

FEASIBILITY STUDY - An investigation to develop a project and definitively assess its desirability for implementation.

FIRM CAPACITY - A plant's load-carrying ability that would probably be available to supply energy for meeting LOAD at any time.

FLASHBOARDS - Temporary panels (usually wood) to raise the water level at an intake.

FLOW-DURATION CURVE - A curve of flow values plotted in, descending order of magnitude against time intervals; usually in percentages of a specified period. For example, the curve might show that over a period of a year, a river flows 500 CFS or more, 10 percent of the time; and 100 CFS or more, 80 percent of the time.

FLYWHEEL -A heavy mass of steel spinning with a turbine and generator adding inertia to the rotating system. Fast changes in load or water supply are smoothed out to create a more uniform rotating speed, thus maintaining 60 Hz.

GENERATOR - A rotating machine that converts mechanical energy into electrical energy.

GIGAWATTHOUR (GWh) - One million KILOWATTHOURS (kWh).

GOVERNOR - An electronic or mechanical device which regulates the speed of the turbine/generator by sensing frequency and either adjusting the water flow or adjusting a balancing LOAD DUMP to keep a constant load on the turbine.

HEAD - The difference in elevation between two water surfaces. GROSS HEAD is the difference between the water level at the intake and the elevation of the free water surface at the turbine (either the nozzle level for an impulse machine or the tailrace level for a reaction machine). NET HEAD is GROSS HEAD less intake losses and pipe friction losses (HEAD LOSS).

HERTZ (Hz) - 1 electrical cycle per second. Usually 60 Hz is maintained.

HORSEPOWER (hp) - The equivalent of 0.746 KILOWATT (kW) or 550 ft-lb/sec. 1 cfs x 62.4lb/ft^3 x 8.8 ft (head) = 550 ft-lb/sec = 1 H.P.

IMPULSE TURBINE - A machine which converts the energy of a jet of water at atmospheric pressure into mechanical energy, usually used to turn a generator. Examples are the Pelton, Turgo and Crossflow turbine.

INCREMENTAL COST - The additional cost incurred when generating an added amount of power or the additional cost of building extra capacity into a project.

INDUCTION GENERATOR - A generator which must be part of a larger system to be controlled. The induction generator is regulated by the electrical inertia and frequency of the larger power system.

INSTALLED CAPACITY - The total of the CAPACITIES shown on the nameplates of the generating units in a hydropower plant.

INTAKE - A structure, either integrated as part of a dam or isolated, and which admits water to the penstock.

KILOWATT (kW) - One thousand watts (W) or 1.34 HORSEPOWER (hp).

KILOWATTHOUR (kWh) - One thousand watthours (Wh) - the amount of ELECTRICAL ENERGY produced or consumed by a one-KILOWATT unit for one hour.

LOAD - The amount of power required at a given point or points in an electric system.

LOAD DUMP - A bank of resistors (heaters) which absorb surplus energy from a generator. A load dump is controlled by a governor to maintain a constant total load on a generator.

LOAD FACTOR - The ratio of the average load to the maximum load during a given period.

LOW-HEAD HYDROPOWER - Hydropower that operates with a head of 20 metres (66 feet) or less.

MAIN BREAKER - A CIRCUIT BREAKER which acts on the main line of a generator's output to control the power (on or off) from the generator to the load.

MEGA (M) - A prefix meaning one million.

MEGAWATT (MW) - One thousand KILOWATTS (kW) or one million watts (W).

NEEDLE VALVE - A tapered, adjustable valve which limits the flow through the nozzle of an impulse turbine.

OUTPUT - The amount of power or energy delivered from a piece of equipment, a station, or a system.

OVERSPEED - A speed higher than the normal operating speed. A turbine/generator in overspeed will produce harmful power surges (unless the MAIN BREAKER acts to put the generator off line) and prolonged operation at overspeed can result in bearing failure and destruction of rotating parts.

PEAKING UNIT - An auxiliary electric power system that is used to supplement the power supply system during periods of peak demand for electricity.

PENSTOCK - A pressure pipe used to carry water to a TURBINE. It can be above ground or below ground, made of steel, plastic, wood or concrete.

POWERHOUSE - The building housing the generating equipment.

POWER FACTOR - The ratio of the actual power used in kilowatts to the voltage x current (in kVa). Resistive loads, such as lights, and heaters have a power factor of 1.0, while loads such as motors and fluorescent lights have a power factor of about 0.8.

PRESSURE (WATER) - The force exerted by water on a unit area of enclosure. The height of water in feet above a point x 0.433 = pressure in psi. The height of water in metres x 10 = pressure in kilopascals (kPa).

PRESSURE RELIEF VALVE - A fast-acting valve which senses pressure increases in the penstock (water hammer) and which releases water from the penstock to reduce the effect of the water hammer.

PSI - A unit of pressure as measured in pounds per square inch.

REACTION TURBINE - A machine which converts the energy of water under pressure to motion. A pressurized case contains the water, which must turn the runner in order to reduce down to atmospheric pressure at the tailrace. The action of a reaction turbine is analogous to a pump running in reverse. Types include the propeller, Francis and Kaplan.

RETROFITTING - Furnishing a plant with new parts or equipment not purchased or available at the time of manufacture or construction. In hydropower development, the term may refer to the installation of electric generating components at existing water facilities to produce electricity.

RPM - Revolution per minute.

RUNOFF - The portion of rainfall or melted snow that flows over the surface and ultimately reaches streams.

RUNNER - The part of a TURBINE, consisting of blades or Buckets on a wheel or hub, which is turned by the action of pressurized water, either by a jet of water (impulse turbine) or by reducing the pressure of the water (reaction turbine).

RUN-OF-THE-RIVER-PLANT - A hydropower plant that uses the flow of a stream as it occurs with little or no reservoir capacity for storing water.

SPECIFIC SPEED - A relationship between rotating speed, power, and head which serves to compare turbines or pumps of different sizes. Also a means of classifying geometrically similar machines.

SPILLWAY - A passage used for running surplus water over or around a dam.

STANDBY POWER - Service that is not normally used, but is available, in lieu of or as a supplement to, the usual source of supply.

STREAM FLOW - The amount of water passing a given point in a stream or river in a given period, usually expressed in CUBIC FEET PER SECOND (cfs), or CUBIC METRES PER SECOND (m^3/s).

SUBSTATION - An assemblage of equipment used to switch and/or change or regulate the voltage of electricity.

SURPLUS ENERGY - Generated energy that is beyond the immediate needs of the producing system.

SYNCHRONIZER - An electrical device which matches the electrical wave forms of two generators to be in phase. The generators so matched operate in parallel.

SYNCHRONOUS GENERATOR - A generator which is capable of regulating its own frequency (speed). It can therefore operate in isolation as a single source of supply to a system. See INDUCTION GENERATOR.

SWITCHGEAR - Apparatus inside a powerplant for controlling the generator output. Usually the switchgear consists of a main breaker and various sensing systems to disconnect the generator from the load if certain faults are detected.

TAILRACE - The channel, downstream of the POWERHOUSE, that carries the water discharged from the TURBINE.

TAILWATER LEVEL - The elevation of the water in the tailrace near the turbine.

TRANSFORMER - A device used to change the voltage of ALTERNATING CURRENT (AC) electricity.

TRANSMISSION - The act or process of transporting ELECTRICAL ENERGY in bulk from a source or sources of supply to other principal parts of a system.

TURBINE - A machine in which the pressure or kinetic energy of flowing water is converted to mechanical energy which in turn can be converted to electrical energy by a GENERATOR.

WATERSHED - The region draining into a stream.

WATER TABLE - The upper limit or surface of the groundwater.

WATER HAMMER - A change in penstock pressure caused by changing the speed of a column of water in a penstock. The result of a rapid valve closure can produce extremely high pressures capable of rupturing a penstock, while the results of extremely rapid valve opening can reduce pressures, causing potential water column separation and vacuum conditions. Water hammer is controlled by using slow acting valves, pressure relief valves, surge tanks or jet deflectors (on impulse machines).

WEIR - A low dam in a stream used to raise or divert the water, or to regulate the flow. Excess flows go over the crest of the weir.

WICKET GATES - Gates at the entrance of a reaction turbine; used to control waterflow.

G. SOURCES OF FINANCING

Most small hydro developers will require a source of financing for their project, because even the most attractive projects will cost several times more than current annual outlays for diesel fuel. Accordingly, the developer must find a source of funds available at acceptable rates and conditions.

The financial concept of small hydro is no different than many other forms of business loans. The outlay of capital allows a certain projected cash flow to occur in future years. In the case of small hydro, that cash flow may be in the form of savings in operating expenses for power generation.

The main difficulty facing the financier is the security on the loan amount. This is simple enough in an urban, business environment, where there are well established values on properties, but in the rural environment of small hydro, property values may be quite low or not defined well enough to provide adequate security for the potential lender.

The lending criteria can be summarized as follows:

(a) the developer must have equity in the project, usually at least 25%;

(b) the developer must be able to show on a net cash flow basis, that there will be sufficient secure revenue to repay the loan. The revenue may come from the developer's job, business, or sales of hydro power;

(c) the lender may require security in the form of personal guarantees, debentures on the property and a right of assignment of incomes;

(d) the lender may also dictate the term of the loan and repayment schedule.

Loans are available at 1 percent to 2 percent above bank prime, depending on the perceived risk to the investor. Fixed and floating rates are available.

The sources of financing include:

Chartered Banks
Trust Companies
Business Banks
Provincial and Federal Development Banks
Private Lenders

The small hydro developer can make a direct approach to any of the above sources, just as he might to obtain any personal or business loan.

The alternative is to go to a Mortgage Broker, who negotiates between the developer and the source of financing. A mortgage broker has the experience to be aware of all potential sources of financing and can relay the criteria to the developer. He can assist the developer in putting together a financeable package (or, telling him if it is not financeable). The one time fee charge is between 1 percent - 2 percent of the loan amount, and is payable only upon delivery of the financing commitment from the lender.

Small Hydro Development Packages

Several companies are offering a one-stop service for financing, project development and design. While they may not do all aspects in-house, they will coordinate the work of the professions necessary. These include:

Synex Energy Resources Ltd.
800 - 1176 West Georgia Street
Vancouver, B.C.
V6E 4A2

Uniteg Energy Corporation
1155 W 48th Avenue
Vancouver, B.C.
V6N 2N6

This is a rapidly changing field and the list may not be up to date at the time of publication.

H. REFERENCES

NOTE:

Attached is a list of references which this chapter's authors would use for Small Hydro Power. This will be supplemented as reference lists are obtained from the individual chapter authors.

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